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APPLICATION OF 2-D FINITE ELEMENT MODELLING TO THE 0997 NEAR-SURFACE STOPE, HOLT McDERMOTT MINE

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Canadian Mine Technology Laboratory

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APPLICATION OF 2-D FINITE ELEMENT MODELLING TO THE 0997 NEAR-SURFACE STOPE, HOLT-McDERMOTT MINE

M.C. Bétournay*

ABSTRACT

This report is related to the application of the finite element modelling technique to approximate the global margin of stability of the 0997 Holt-McDermott near surface stope using various values of the Hoek and Brown failure criteria parameters.

Conclusions are presented on the stability of this stope based on the finite element technique, the sensitivity of the failure criteria parameters and comparison of these results to earlier stability assessment based on analytical considerations.

KEYWORDS: finite elements, numerical model, near-surface opening, surface crown pillar.

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MODÉLISATION PAR ÉLÉMENTS FINIS, 2-D, DE L'OUVERTURE SUPÉRIEURE 0997 DE LA MINE HOLT-McDERMOTT

M.C. Bétournay*

RÉSUMÉ

Ce rapport d'écoule de l'application de la technique de modélisation par éléments finis pour approximer la marge de stabilité globale de l'ouverture supérieure 0997 de la mine Holt-McDermott avec l'utilisation de plusieurs valeurs de paramètres du critère de rupture Hoek et Brown.

Des conclusions sont présentées sur la stabilité du chantier basé sur la technique des éléments finis, la sensibilité des paramètres du critère de rupture, et la comparaison de ces résultats avec des évaluations de stabiolité analytiques antérieures.

MOTS CLÉS: éléments finis, modélisation numérique, ouverture peu-profonde, pilier de surface.

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1. INTRODUCTION

A cooperative, shared cost ground investigation between American Barrick Resources Corporation and CANMET/MRL has been carried out at the Holt-McDermott Mine, situated in Northeastern Ontario, near the Quebec border, Figure 1.

The study was carried out within the general framework set for CANMET/MRL's involvement in cooperative research. Accordingly, the non-consultant, research role CANMET/MRL carried out, has the following objectives:

- to establish applied rock mechanics reference data which can be reviewed by the company and consultants retained by the company for making mine planning and operational decisions, providing that the study results are considered by the company and consultant as pertinent.

- to develop new applied investigational and analytical methods and monitoring equipment suited to the specific requirements of the study and for general use by the industry.

- to transfer the latest and most up-to-date developments in rock mechanics technology relevant to the specific requirement of the study.

The purpose of this report is three fold:

It is meant to be an example of the usefulness of numerical modelling techniques, presently the best method to evaluate total rock mass stability. Displacement of the rock mass, stress distribution and conditions of the rock mass are discernable under specific stope geometries and location.

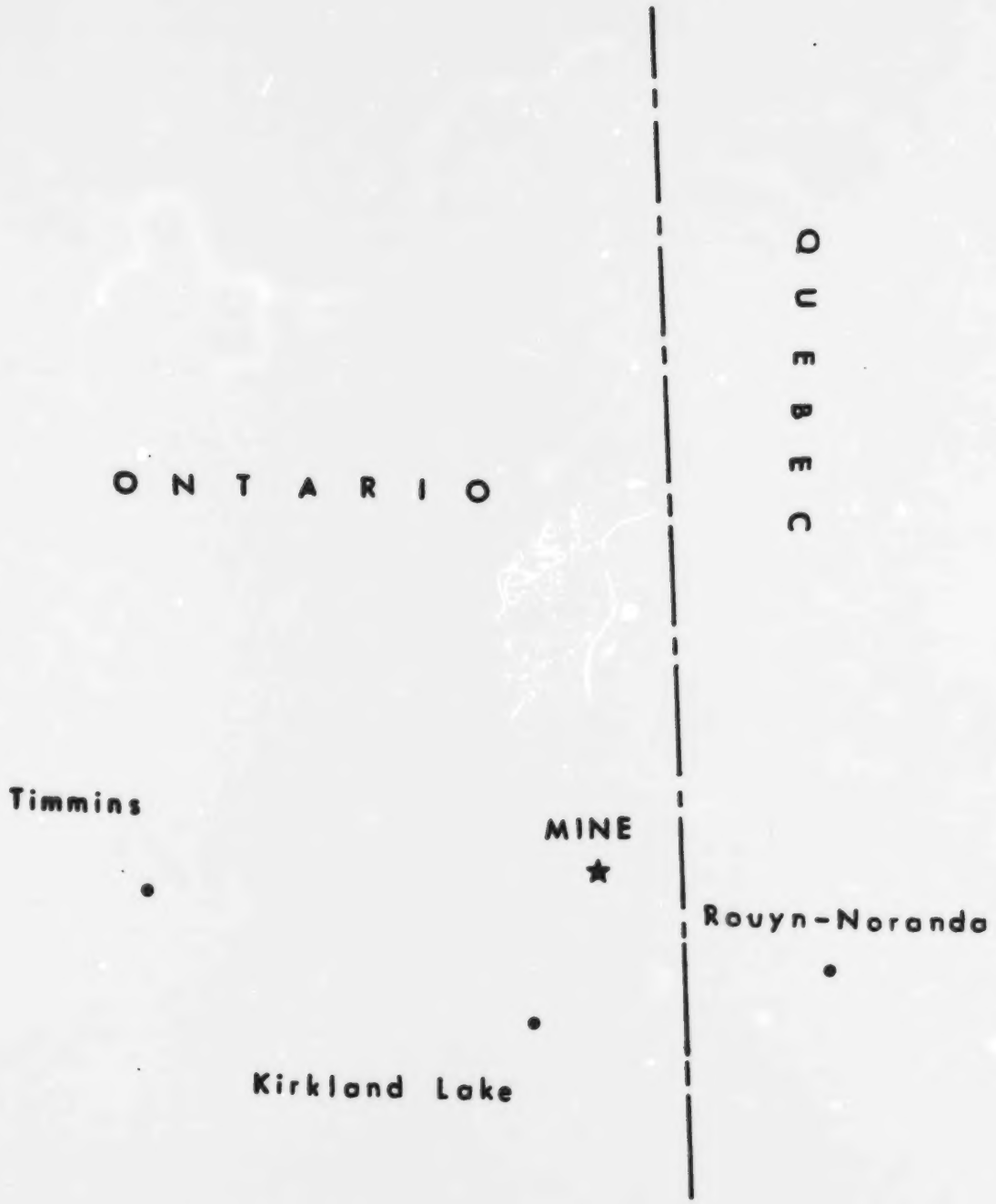


Figure 1. Holt-McDermott mine location.

This particular modelling provides the operators with specific examples of conditions using representative site parameters.

The modelling also serves to complement the site visit report (1) which discussed surface crown pillar conditions at length in an analytical and not numerical context.

Finally, a parametric study is presented for the benefit of recognizing the effects of varying stability parameters within a representative range of values.

The main rock unit on site is basalt that has been faulted by a thoughgoing E-W fault which contains fault gouge. Secondary, cross-faults in the footwall of the orebody, terminate on trace of the main fault.

The orebody is delimited by the grade of the disseminated gold.

A graphite schist zone of variable lateral thickness, up to 30 m, parallel to the orebody in the footwall.

A longhole mining method will be used to excavate the stope. The opening will not be backfilled.

2. FINITE ELEMENT MODEL

Several numerical modelling techniques exist (finite elements, boundary elements, distinct elements, etc.), but the small scale rock movements, block sizes and heterogeneous rock types found at the site are the basis for adopting finite element modelling in search of the most representative results.

The model used, MSAP2D (2), is a numerical model developed for use on personal computers equipped with mathematical coprocessor and fixed disk. It is a two-dimensional linear elastic program. Displacements of nodal points as well as stresses of prescribed location, are outputed. The

possible locations for stress calculation include the center and the mid points of the four sides of each elements. Displacement as well as major and minor principal stresses are plotted in vectorial form. Three failure criteria are available for parametric studies and to verify the safety level: Mohr-Coulomb, Drucker-Praeger and Hoek and Brown. The safety levels are separated into zones of "failures" ($F_s < 1$), "critical" zones ($F_s = 1.0 - 1.4$) and "safe" zones ($F_s > 1.4$). (These definitions and values are fixed and were established by the developers of the program).

This model permits the use of up to 7 geomechanical materials. The MSAP2D version used for this report is limited to 200 elements. Although several times more elements are usually used in modelling a problem of this size, it was felt that a good perspective on the problem could be obtained with it, as the results will show.

Applying a 2-D model takes for granted that the section used (transversal) is representative and that the third dimension (longitudinal) is actually long enough to resemble the infinite length assumed by the model. Since the 0997 stope will have a longitudinal span of over 80 m, the model's transverse section, if it is central, most likely meets this representation.

The model is 120 m wide and 160 m high, Figure 2. A 40 m high (vertically), 6 m wide (horizontally) opening within the geomechanical mine setting was modelled. The opening, 40 m below surface, dips 70° and is situated in the ore zone of the mine. The geomechanical materials used are shown in Figures 3, 4.

The dimensions of the opening reflect the 2-1-0997 stope geometry, at its widest expanse. A total of 194 quadrilateral isoparametric elements were used, with 229 nodes, Figures 5-7.

The immediate footwall and hangingwall, and the surface crown pillar areas have a denser element grid, as these were areas of concern.

The in-situ stress condition was applied as the loading case.

Although no in-situ stress measurements were taken, experience has shown that the major principal stresses in the Abitibi-Témiscamingue Greenstone Belt is 2 to 3 times the minor principal stress (the vertical stress is the gravity load at shallow levels). The former is nearly horizontal and always makes a near perpendicular angle with major local faults (3)(4).

For these reasons, gravity is the vertical stress and the major principal stress is the horizontal stress on this model. The model is along a transverse section, oriented N-S, while the McKenna Fault dipping north runs parallel, E-W, with the longitudinal axis of the orebody. The following stress values are used:

$$\sigma_y = \gamma z$$
$$\sigma_x = 2\ (\sigma_y)$$
$$\sigma_z = \nu\ (\sigma_x + \sigma_y)$$

where

γ = rock density
z = depth
ν = Poisson's ratio = 0.2

σ_y = vertical stress
σ_x = horizontal stress, in the section
σ_z = horizontal stress perpendicular to the section

The rock mass was separated into five distinct geomechanical zones, Figure 3, based on the site visit (1) and modes of behaviour:

Zone	Horizontal Thickness	Sector
1	edge of model to zone 2	far-field hangingwall
	zone 5 to edge of model	far-field footwall
2	4 m	immediate hangingwall
	6 m	immediate footwall
3	2.5 cm	fault gouge
4	6 m	ore zone
5	10 m	graphite schist

Figure 2. Outline of numerical model dimensions.

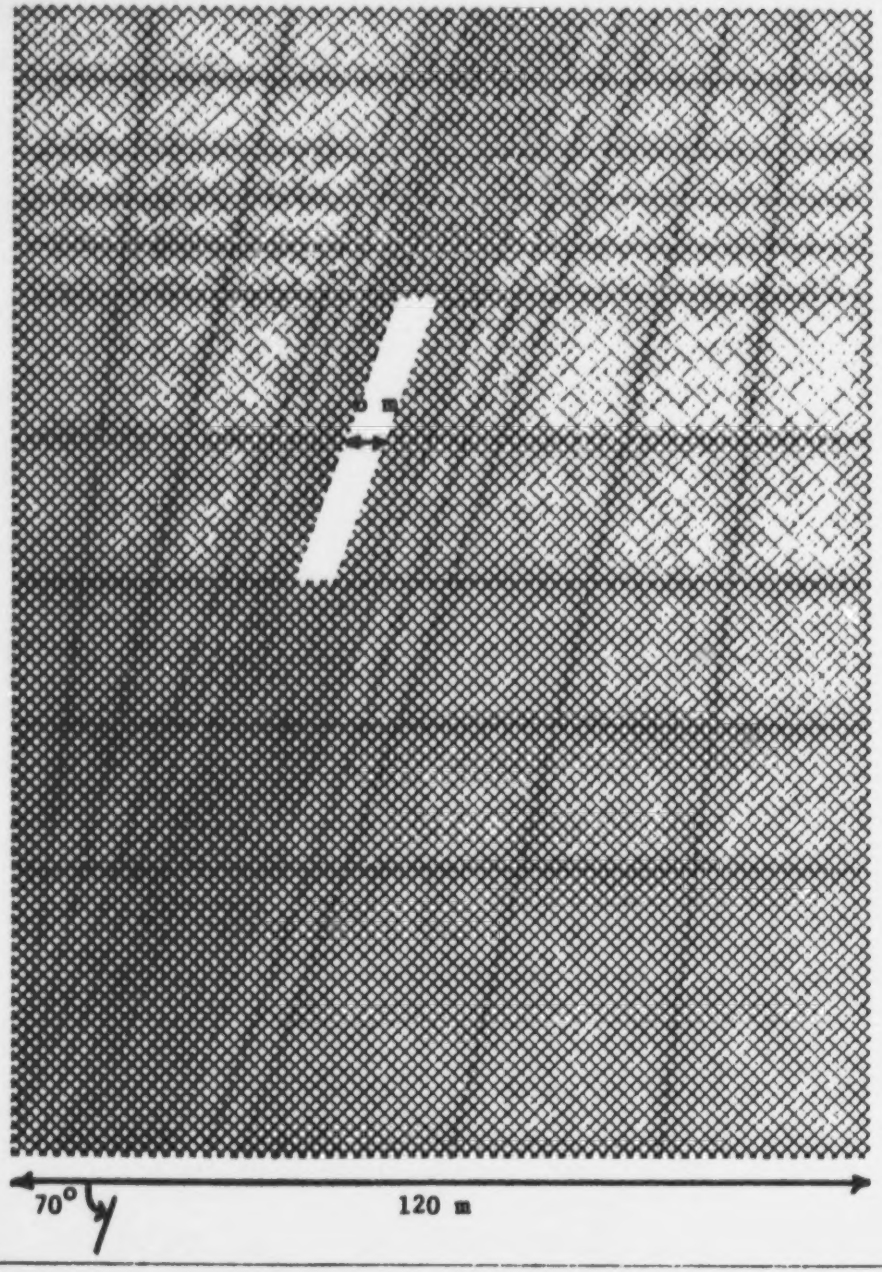


Figure 3. Separation of the model into geomechanical zones.

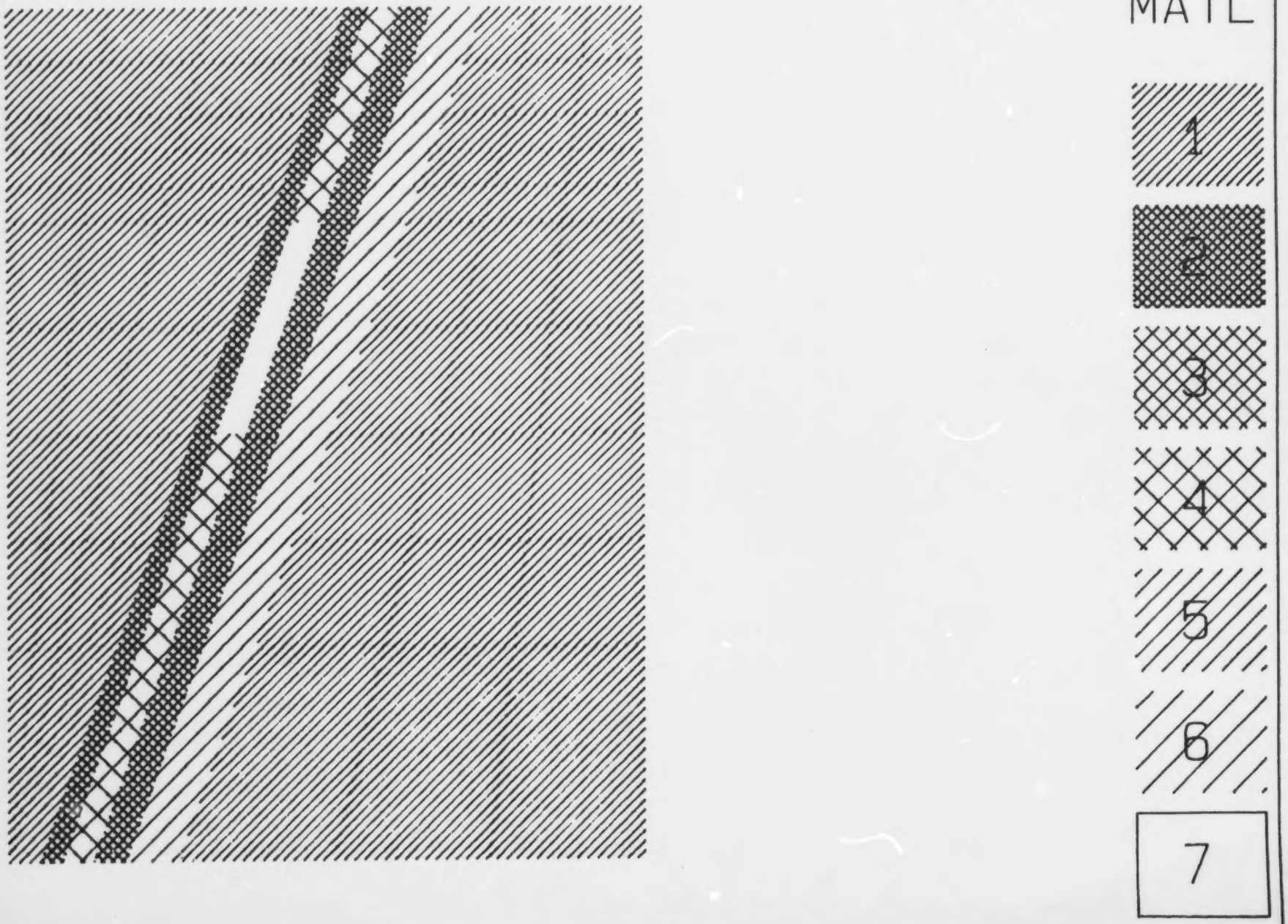


Figure 4. Close-up of geomechanical zones in the surface crown pillar area.

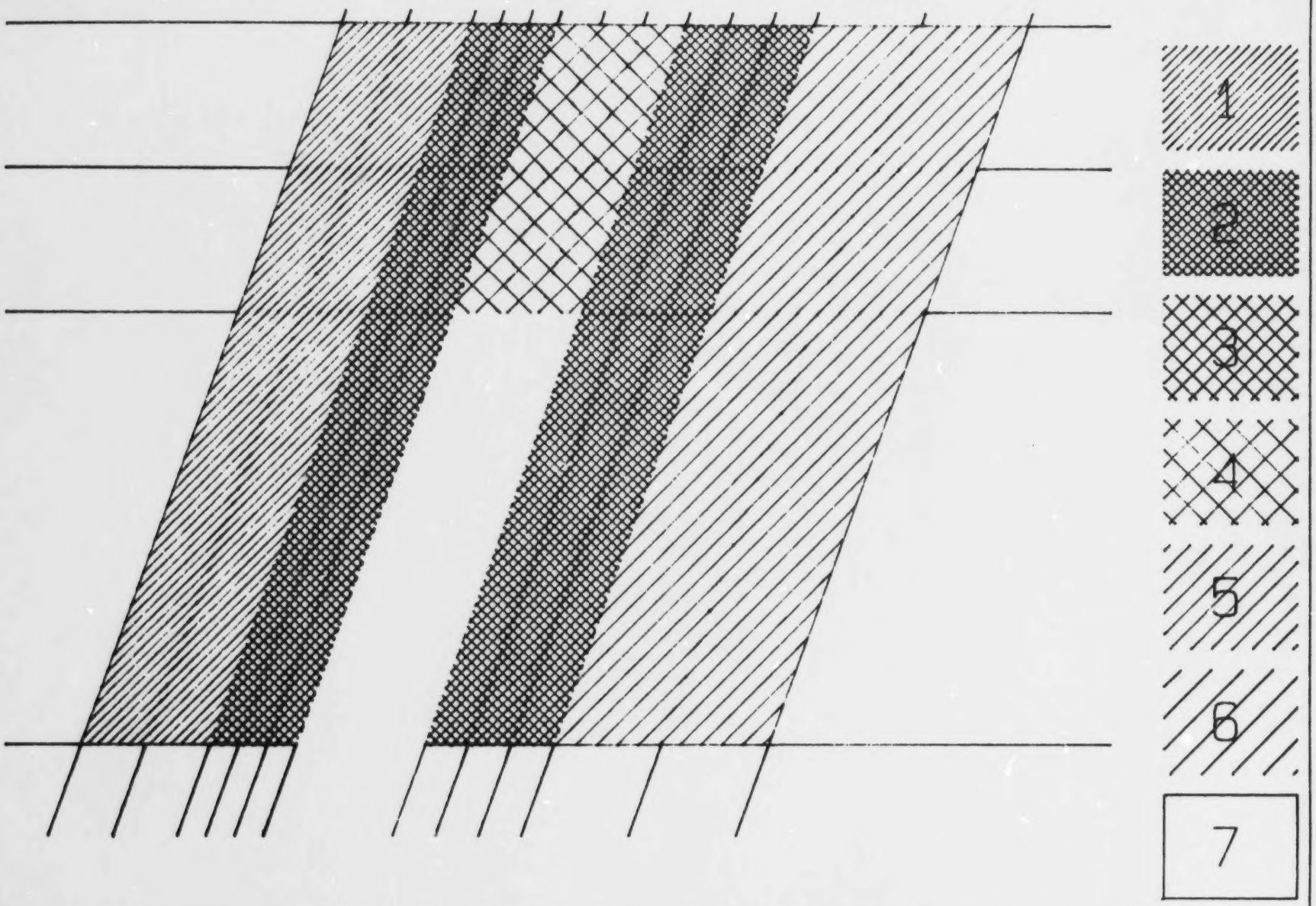
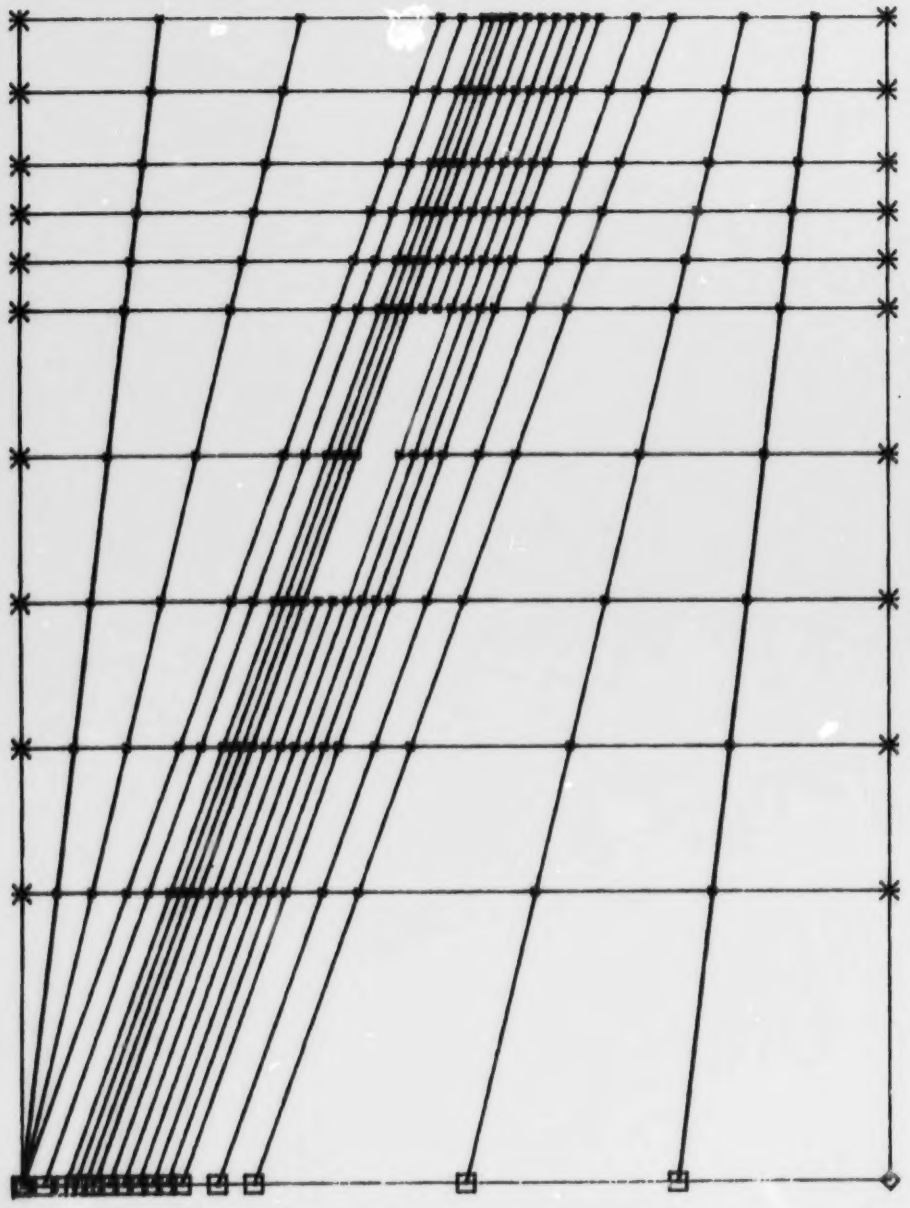


Figure 5. Model mesh. Notice the higher density of elements in the surface crown pillar, hanging and footwalls.



◇ fixed • free ✳ x fixed □ y fixed

Figure 6. Mesh element and node numbering.

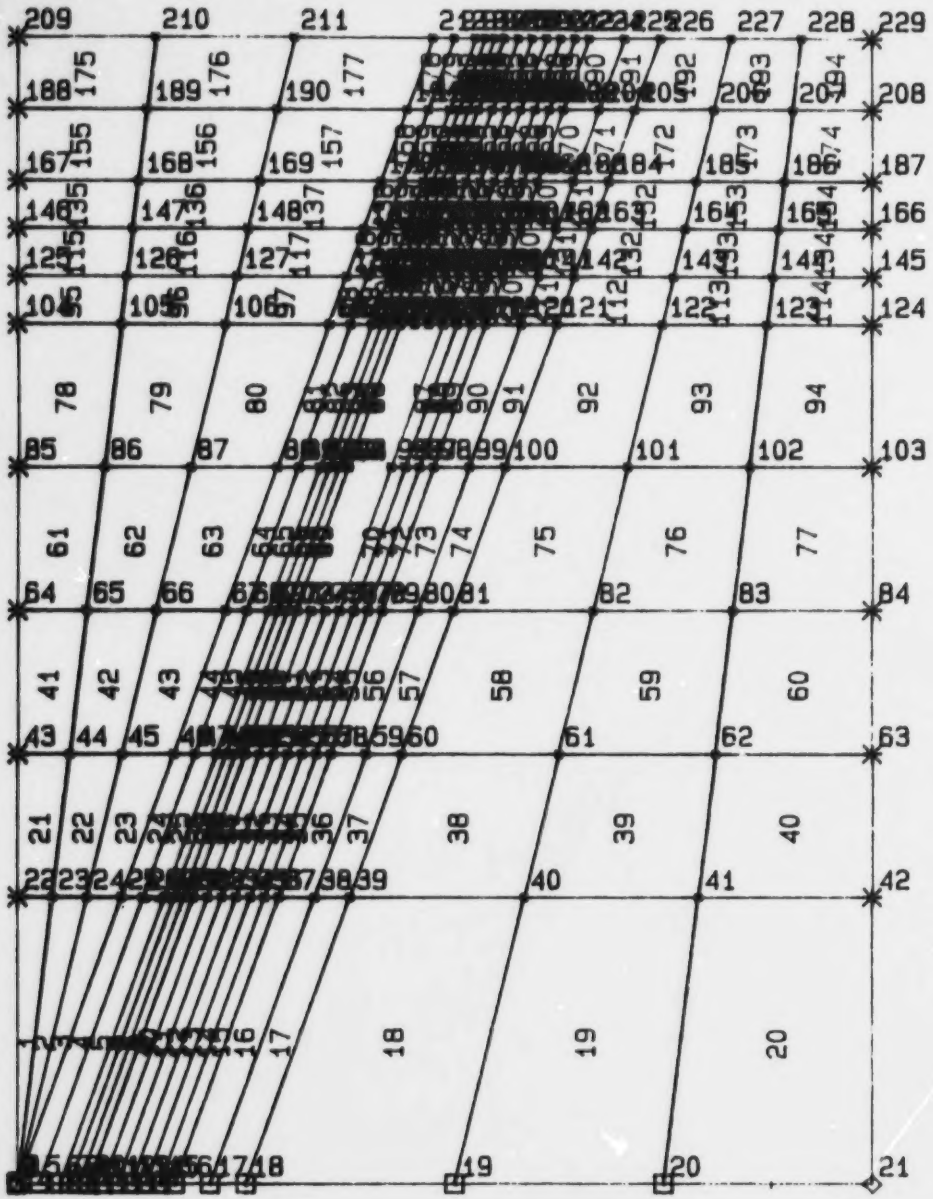
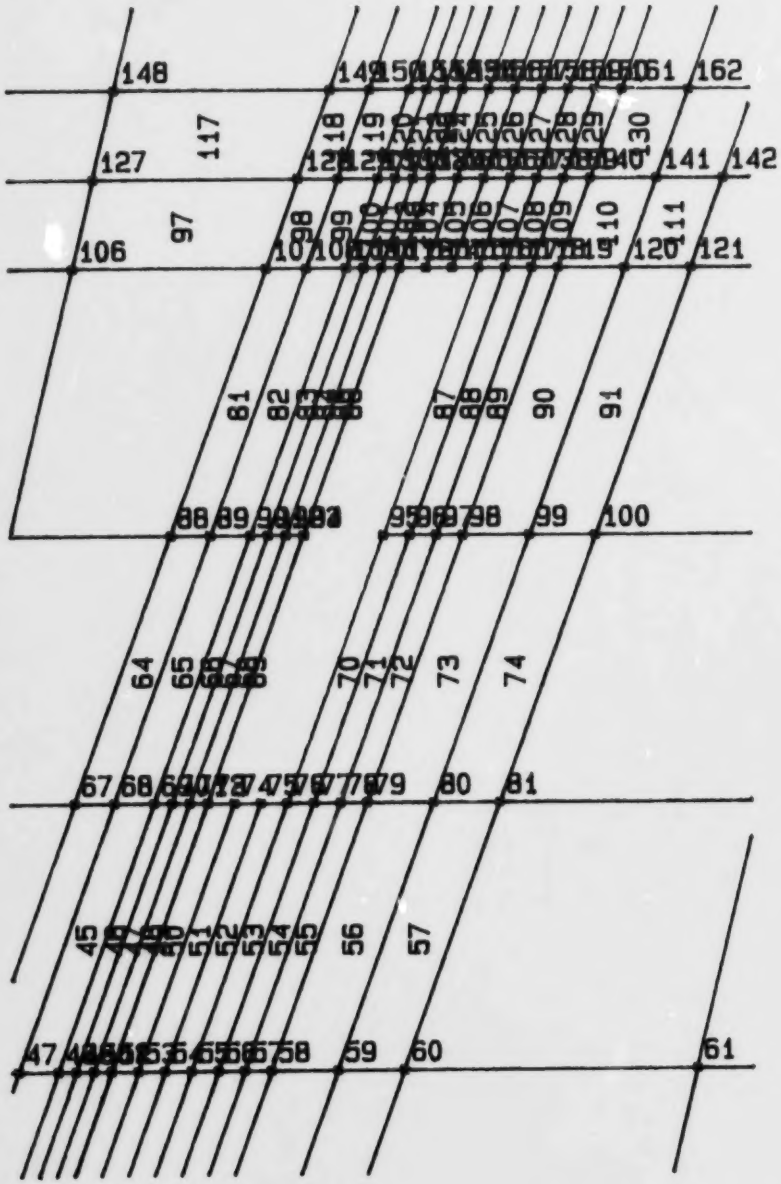


Figure 7. Close-up, mesh element and node numbering around the opening.



◇ fixed ▪ free ✱ x fixed □ y fixed

The thickness of the sectors were taken at their largest extent, to model a worst case situation.

Table 1 lists the material density, Poisson's ratio and modulus of elasticity of each sector's rock material for the numerical model requirements.

Future openings which will adjoin stope 0997 were not included in this model, only the results of the upper opening activity were required at this point in time to assess surface crown pillar stability.

Future adjoining openings in this section, and their effects can be included in the model (e.g. the 3-1-1015 stope).

3. RESULTS AND DISCUSSIONS

The results are presented in Appendices 1-8. Appendix 1 shows the stresses at the center of the elements and total displacements at the nodes, for the opening modelled, under in-situ stress conditions.

The displacements of the rock mass due to the creation of the opening are towards the openings. They are highest at the opening periphery, stope half-height, at the hangingwall and footwall, mainly in a horizontal fashion. The surface crown pillar is also displaced towards the opening, but negligibly. The value of the mid-height elastic displacements reach 2.4 mm horizontally.

The stress follows the expected distribution for a long narrow opening intersecting the major principal stress at a high angle. Compressive stresses are found at the top (surface crown pillar) and bottom of the opening. Tensile stresses occur in the sides of the opening, the lower footwall corner and deep in the surface crown pillar at the footwall upper corner.

The tensile stresses are highest at the periphery of the opening,

TABLE 1

MATERIAL PROPERTIES OF THE GEOMECHANICAL SECTORS
AROUND STOPE 0997

Zone	Sector	γ kN³	ν	E GPa
1	Far-field hanging and foot walls	27.0	0.20	70
2	Immediate hanging and foot walls	26.0	0.23	55
3	Fault gouge	20.0	0.38	0.12
4	Ore zone	27.0	0.21	65
5	Graphite schist	25.0	0.32	20

but extending 8.5 m and 3 m respectively in the hangingwall and footwall of the opening. Maximum tensile stress values of 0.49 MPa and 0.58 MPa respectively occur in the hangingwall and footwall. The lower footwall tensile stress value is 0.16 MPa while the surface crown pillar area under tensile stress registers 0.38 MPa.

The highest compressive stress around the opening periphery is 3.3 MPa in the lower footwall and 6.14 MPa in the surface crown pillar.

Applying another lower, tectonic stress ratio,

$$\sigma_H = 1.7\ \sigma_v,$$

reduces the depth of tensile stresses in the hangingwall and footwall of the opening but not the values, at the opening, in the surface crown pillar or at the lower footwall.

The Hoek and Brown failure criterion (5) was used to evaluate the margin of stability under the chosen geomechanical sector setting and tectonic stress ratio, where

$$\sigma_H = 2\sigma_V$$

The coefficient values found in Table 2 were used as basic values approximating actual conditions. This failure criterion was adopted because it is based on rock quality, and because the operator with field surveys and lab tests can assess the m and s values to use. Complete lab and field surveys will provide more accurate values.

These are rock mass values, obtained from examination of site conditions (1), consideration of lab tests (6), application of experience and consideration of the behaviour m and s reflect. The selection of parameters was approached from the conservative side. In particular, the m and s values of the immediate foot wall reflect the potential for ravelling (weaker in tension). Even though the hanging wall might be better than the footwall, conservative values were also used. The graphite schist zone is

TABLE 2

m & s COEFFICIENTS, HOEK AND BROWN FAILURE CRITERION, GEOMECHANICAL SECTORS

Zone	Sector	m	s	σ_c MPa
1	Far-field hanging and footwalls	3.8	0.04	230
2	Immediate hanging and footwalls	2.8	0.006	100
3	Fault gouge	0.05	0.00001	0.15
4	Ore zone	3.2	0.02	200
5	Graphite schist	0.6	0.0005	30

very weak in tension and weak in compression.

The use of the base values indicate that zones with $F_s < 1$ are possible, at the opening periphery, hangingwall (4 m wide) and footwall (2 m wide) and adjacent to the surface crown pillar, Appendix 2.

Areas with a F_s between 1.0 and 1.4 occur in the lower schist area and lower footwall periphery. The small portion between the periphery and schist area is "stable".

A small portion of the surface crown pillar, in the footwall side, is under a $F_s < 1.0$.

The fault gouge is in the "failed" condition for its entire length.

Under these m and s values, the zones with a $F_s < 1.4$ have occurred where the tensile stresses are higher than 0.35 MPa.

For the modelling performed using base values, the surface crown pillar stope 0997 is, for the most part, under a $F_s > 1.4$; only a small portion deep in the footwal has a $F_s < 1.0$.

But it must be realized that the upper footwall and hangingwall represent "unstable zones". Failures there widen the stope directly under the surface crown pillar and could lead to degradation of ground conditions especially in the footwall.

Parametric studies were also carried for each of the weaker zones, #2 and #5. The purpose of this study is to alert the reader to the effects of small changes in the m and s values especially when the values are in the lower range. Appendix 3 contains a cross section of m values for zone 2. Appendix 4 presents the variation of s values for zone 2. Appendix 5 has combined m and s variations for zone 2. Likewise, Appendices 6-8 present the separate effects of m, s values and the combined effects for zone 5. The range of m and s values used is within reasonable

limits of variation for these materials. The combined effects of these parameters must be paired, i.e. if m is improved, so is s.

Varying the m value in the immediate hanging and foot walls from m = 1.4 to m = 3.2 changes the F_s from > 1.4 to < 1.0 in the lower foot wall. A deeper zone of F_s < 1.0 occurs in the upper hanging wall and a small portion inside the surface crown pillar reaches the F_s < 1.0 level. These areas are all under tensile stresses.

A change in value from s = 0.02 to 0.1, for this area improves stability conditions in the lower foot wall above F_s = 1.4 and reduces the depth of the F_s < 1 zone in the upper foot wall.

It is unlikely, however, the zone 2, especially the footwall area, can reach such a high value because of the ravelling conditions that can occur there.

Combined higher values of m and s for zone 2, provide a stability assessment similar to the s value alone. Combined lower values provide a less stable lower opening footwall, and a F_s < 1. This situation is slightly worse than for the s value alone.

In the graphite schist zone, which is only under compression, varying m values, has great effects. At worst (highest m value, 0.1), most of the zone up to the surface crown pillar will have a F_s < 1. At best, m = 1.0, only a small area is not under F_s > 1.4.

All the s values yield the same stability results, Appendix 7.

Combined m and s values resemble closely the results for m variations only, Appendix 8.

The stability results obtained by varying m and s values in tensile and compressive zones follow the influence of the m and s values on the failure envelope, Figure 8.

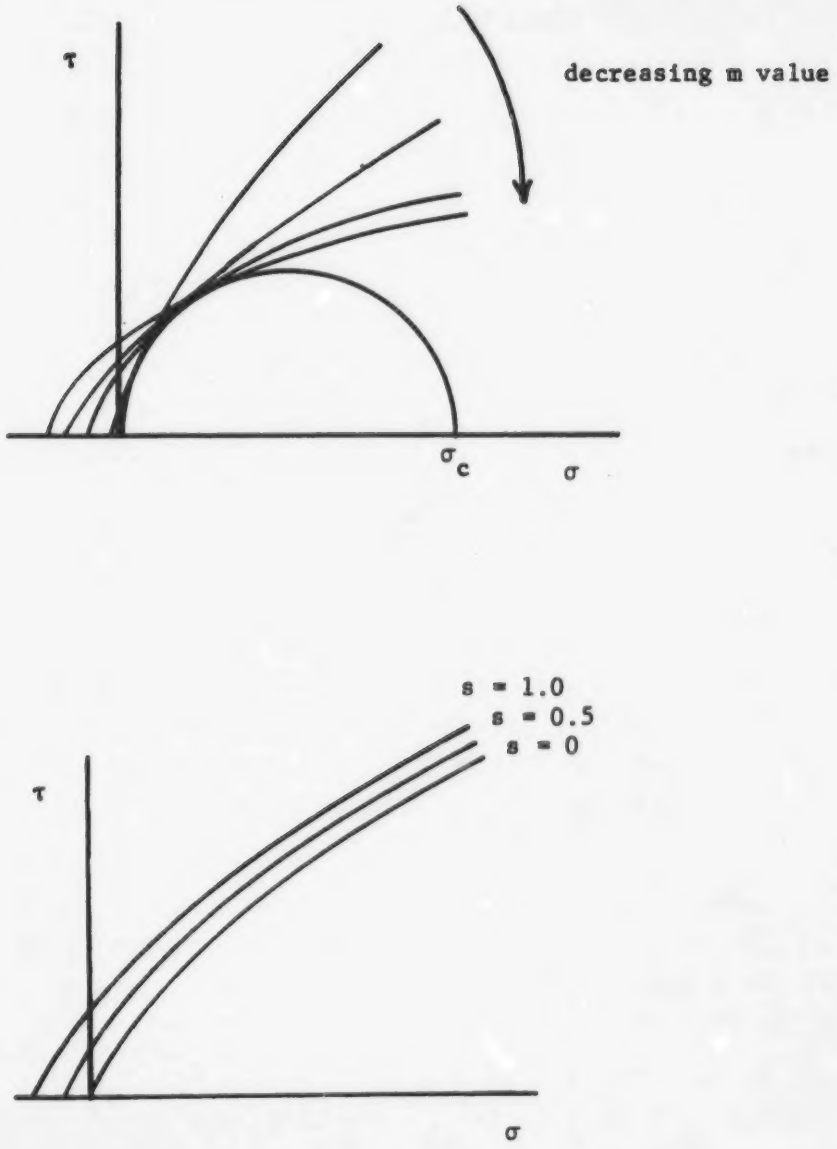


Figure 8. Influence of the value of the constants m & s on the shape of the Mohr failure envelope (7).

The results of this modelling mirror the findings of the previous report using analytical methods (1). Although compression is present in the surface crown pillar area, ground support should be emplaced to maintain a tight rock mass. A method such as cable bolting can keep the mass from degrading seriously.

Although blasting effects can only be alloted an empirical reduction in m and s, field surveys can evaluate the volumetric extent and nature of the damage.

CONCLUSIONS

1) Application of finite element modelling provides additional information for use in appraising the global stability of the underground openings of concern.

2) Under tectonic stress conditions representative of Canadian Shield conditions, the modelling indicates zones of concern for stability, around the periphery of the opening and, to a lesser extent, in the surface crown pillar.

3) Using a representative set of Hoek and Brown failure criteria parameters, three zones have potential stability problems: the upper immediate footwall/hangingwall, fault gouge zone and graphite schist zone.

4) Since possible instabilities occur in the vicinity of the surface crown pillar, proper support should be emplaced to prevent degradation of pillar conditions.

5) A parametric study indepently varying the parameters indicates that the zones of stability concerns under tensile stresses will show better stability with lower m values, higher s values. Those zones of stability concerns under compressive stress will show better stability with high m or s values. This follows expected influence of the Hoek and Brown paramaters on the failure envelope.

6) Accuracy must be used when selecting m and s values in their lower ranges. A small difference in value can bring on overestimation or underestimation of stability.

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APPENDIX 1

STRESSES AND DISPLACEMENTS AROUND 0997 STOPE

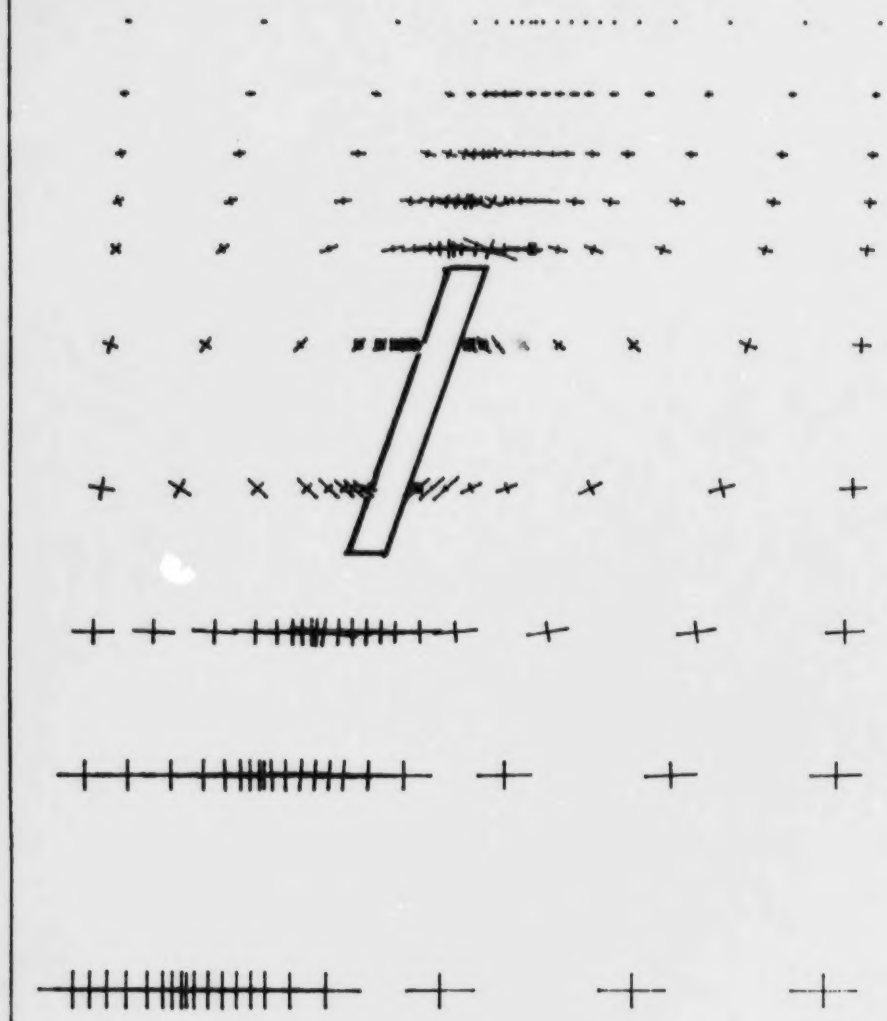
P. 24 Figure A1-1 - Stresses at the centre of the elements. Stress ratio: horizontal stress twice the vertical stress.

P. 25 Figure A1-2 - Close up of stresses around opening periphery. Stress ratio: horizontal stress twice the vertical stress.

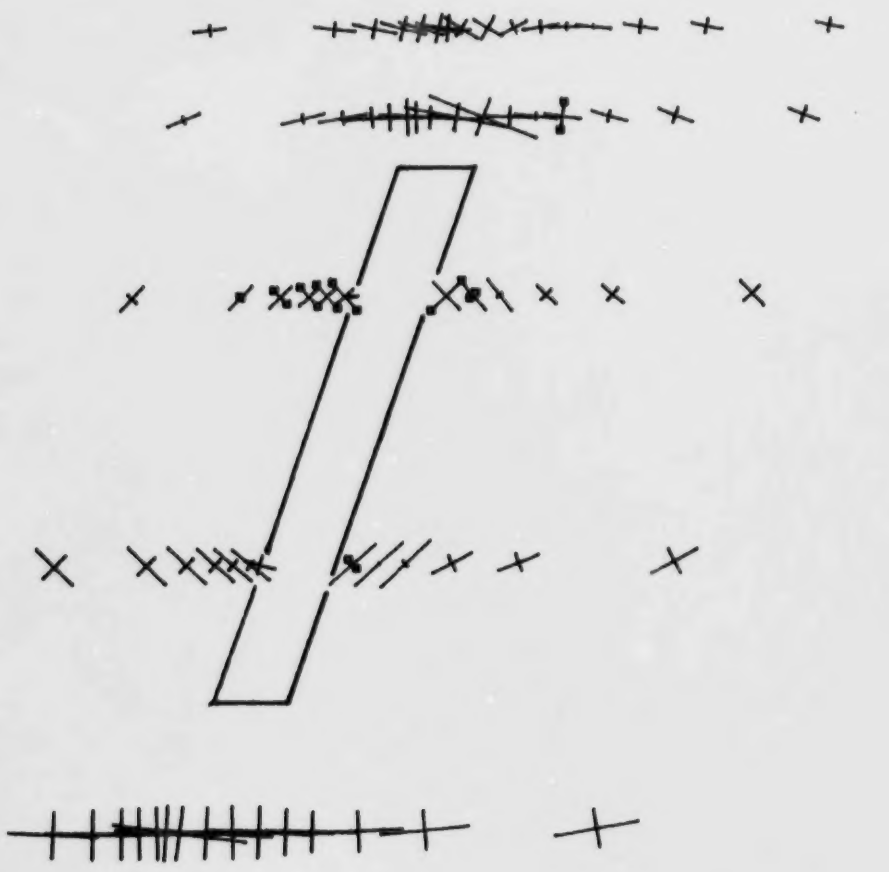
P. 26 Figure A1-3 - Stress at the center of the elements. Stress ratio: horizontal stress 1.7 times the vertical stress.

P. 27 Figure A1-4 - Close-up of stresses around opening periphery. Stress ratio: horizontal stress 1.7 times the vertical stress.

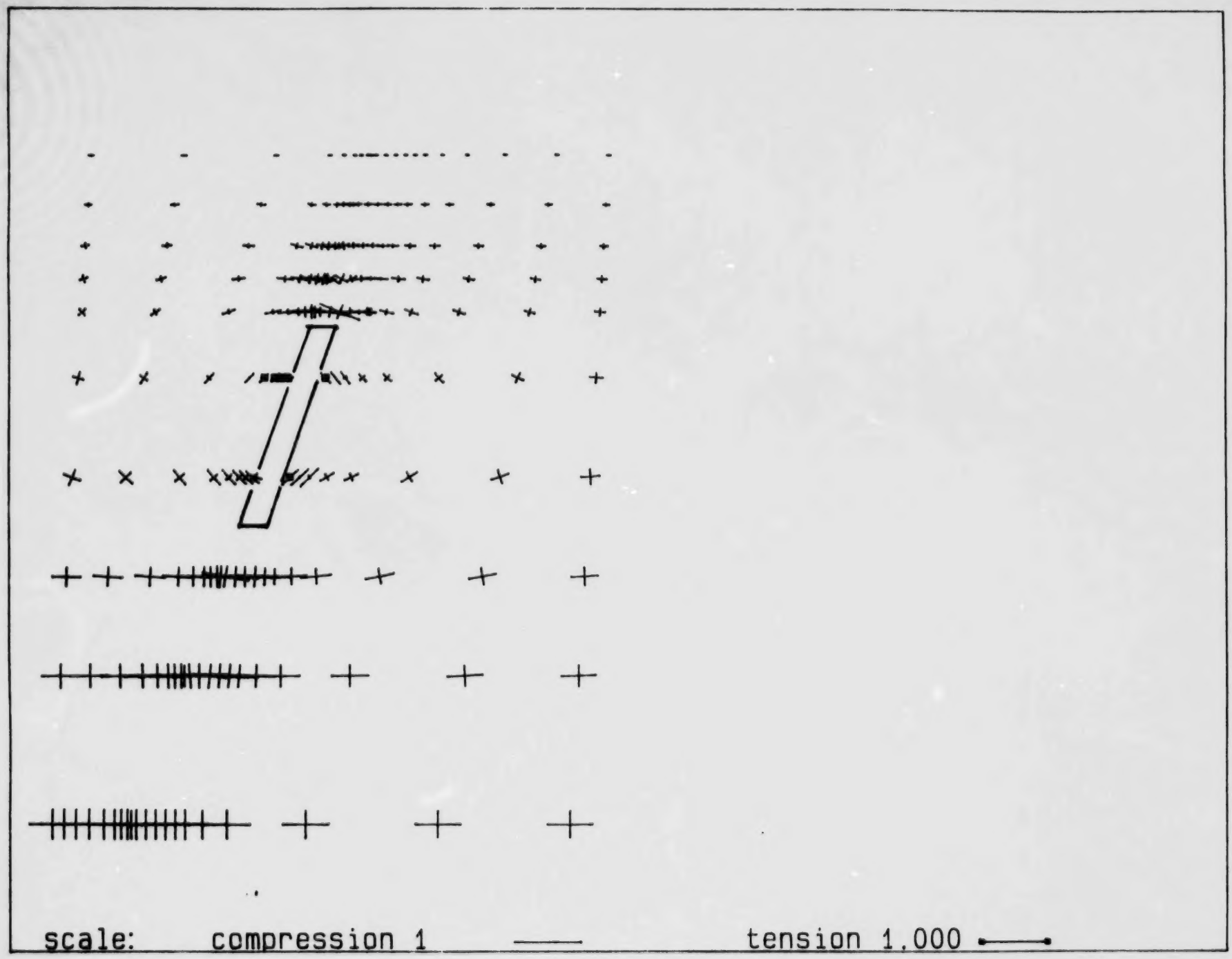
P. 28 Figure A1-5 - Elastic displacements at the mesh nodes.

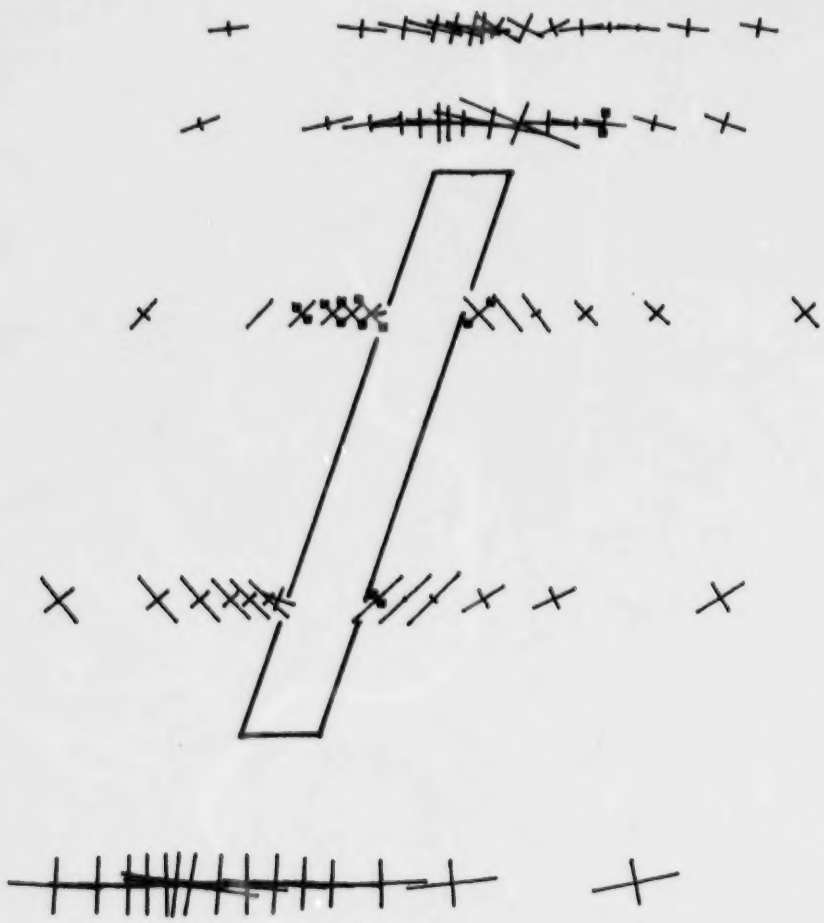


scale: compression 1.000 tension 1.000

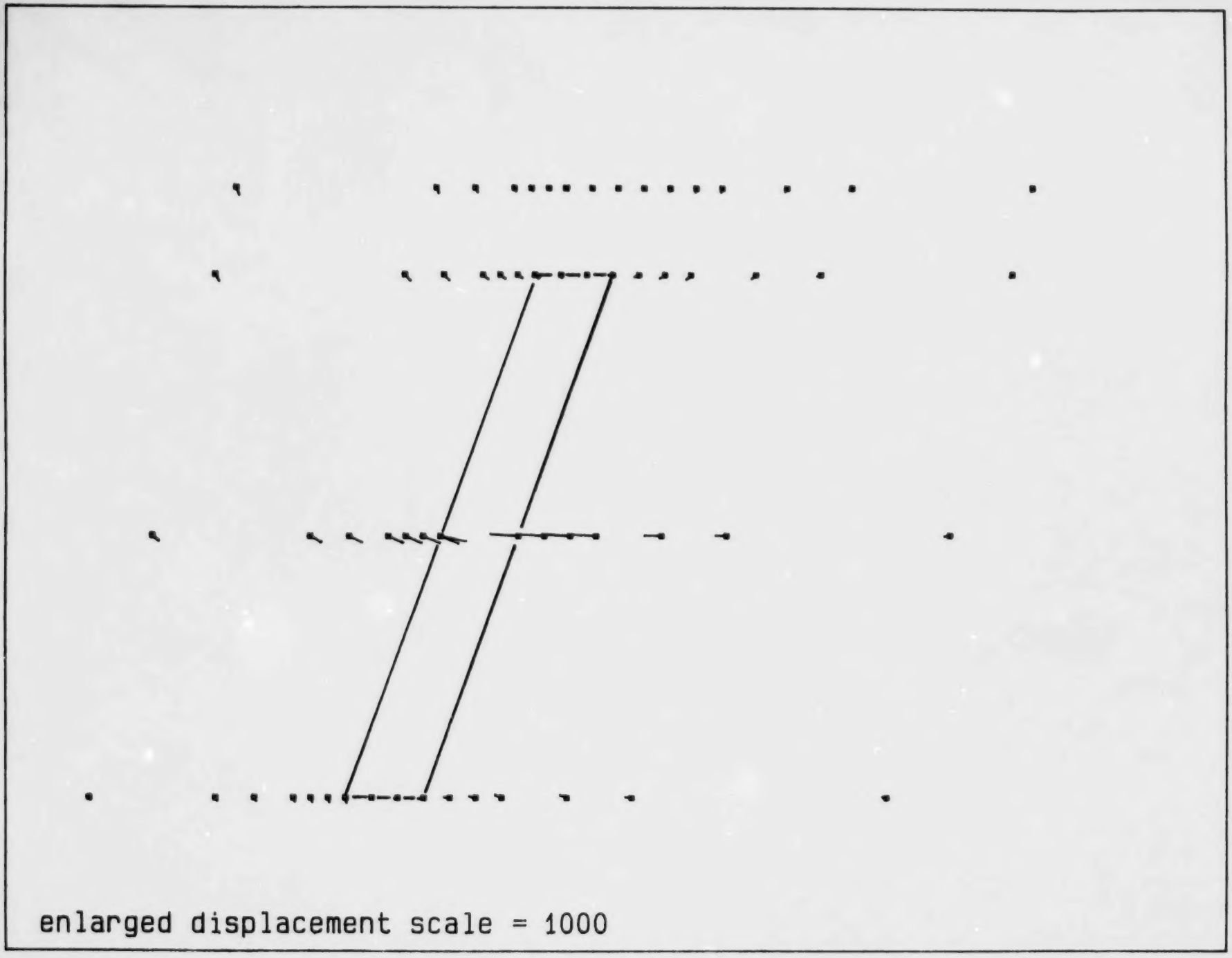


scale: compression 2 tension 8


scale: compression 1
tension 1.000



scale: compression 2 tension 8


enlarged displacement scale = 1000

APPENDIX 2

STABILITY ANALYSIS STOPE 0997 USING m & s BASE VALUES

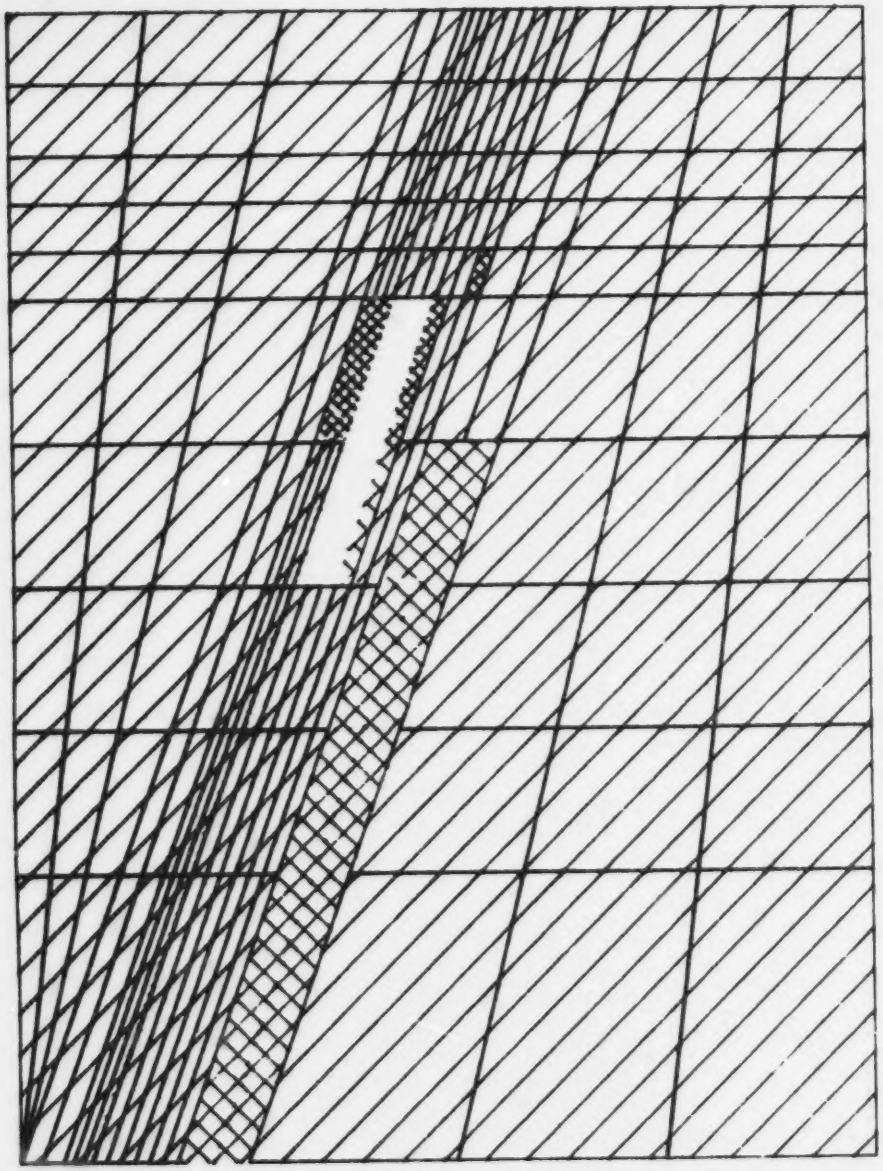
P. 31 Table A2-1 - Hoek and Brown coefficients used for the basic stability analysis.

P. 32 Figure A2-1 - Basic stability analysis with Table A2-1 coefficients.

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

CRITICAL

SAFE

APPENDIX 3

STABILITY ANALYSES USING DIFFERENT m VALUES, IMMEDIATE HANGING WALL/FOOT WALL

P. 35 Table A3-1 - Higher m value (3.2), immediate hanging wall/foot wall.

P. 36 Figure A3-1 - Corresponding stability analysis, higher m value, immediate hanging wall/foot wall.

P. 37 Table A3-2 - Base m & s values.

P. 38 Figure A3-2 - Corresponding stability analysis, base values.

P. 39 Table A3-3 - Lower m value (1.4), immediate hanging wall/foot wall.

P. 40 Figure A3-3 - Corresponding stability analysis, lower m value, immediate hanging wall/foot wall.

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
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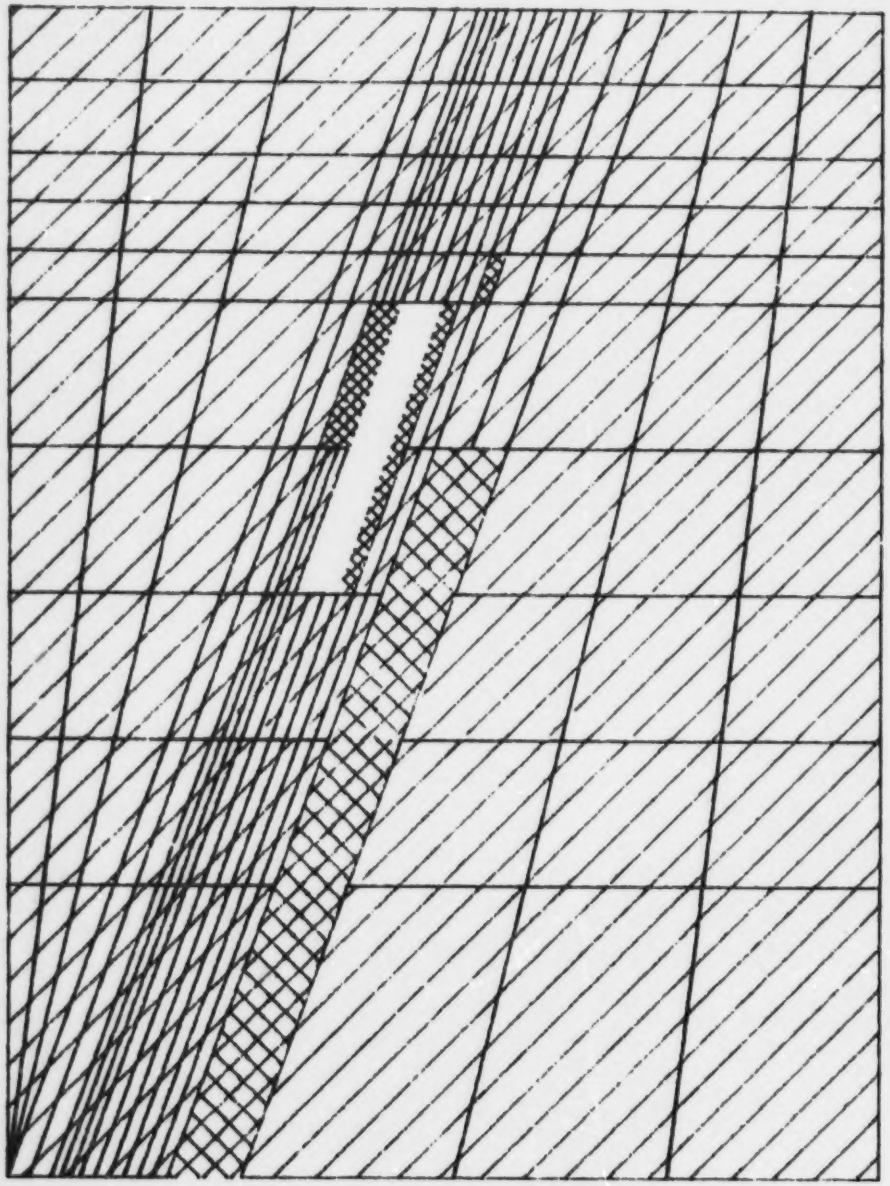
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

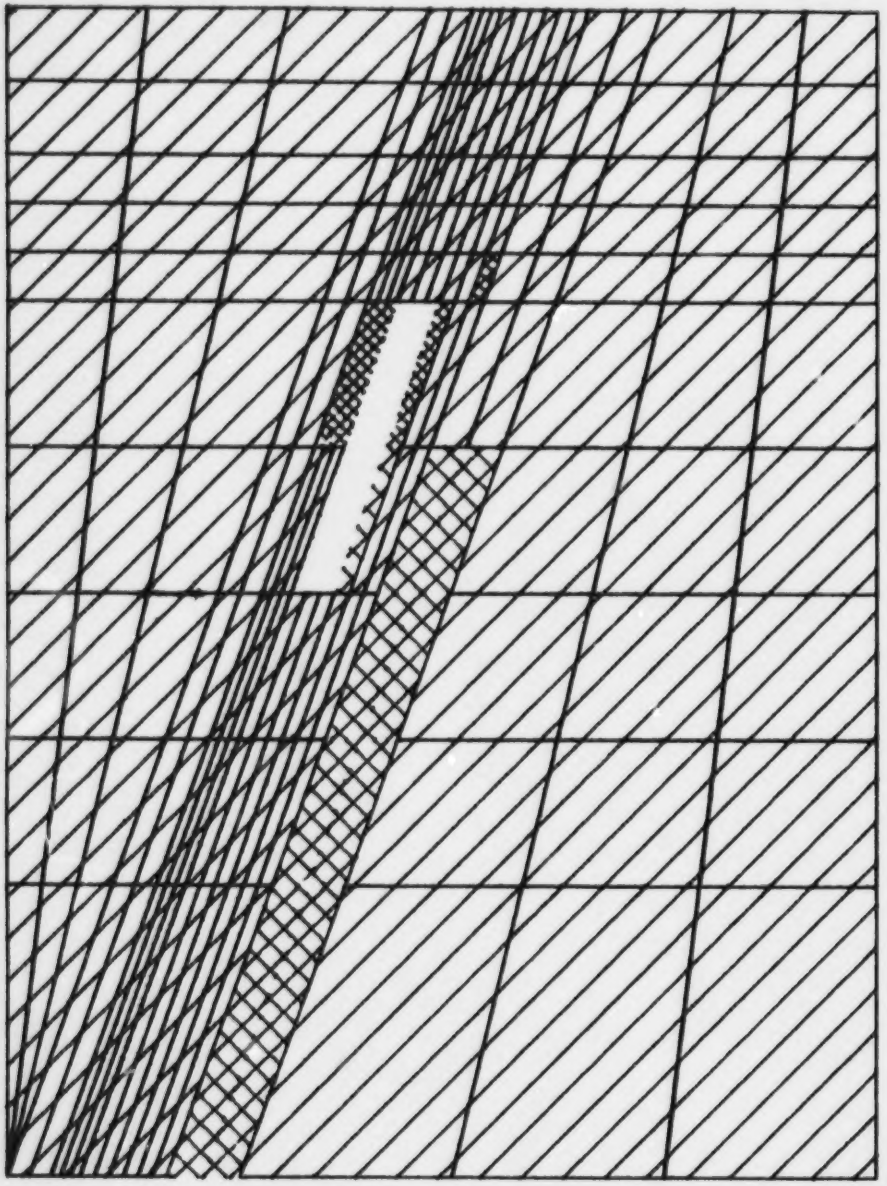
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

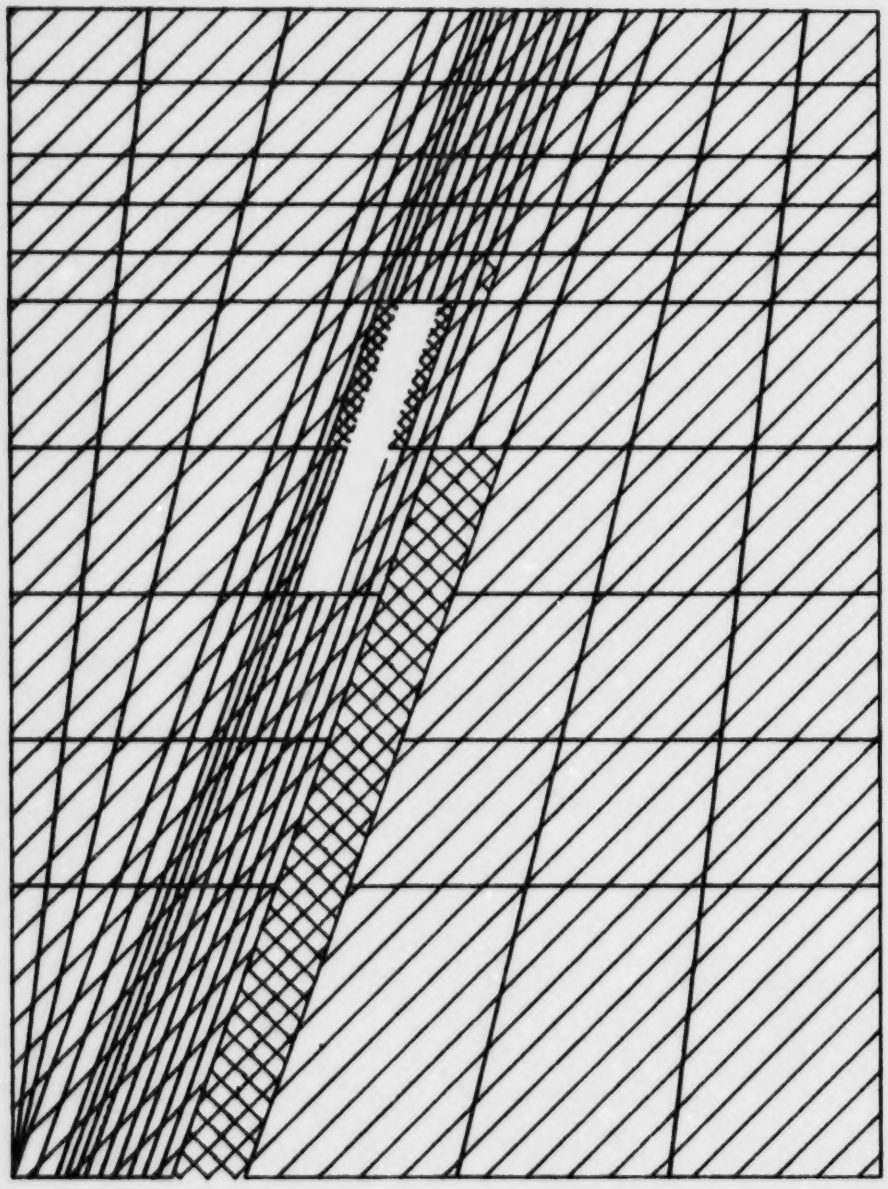
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	1.4	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

CRITICAL

SAFE

APPENDIX 4

STABILITY ANALYSES USING DIFFERENT s VALUES, IMMEDIATE HANGING WALL/FOOT WALL

P. 43 Table A4-1 - Higher s value (0.02), immediate hanging wall/foot wall.

P. 44 Figure A4-1 - Corresponding stability analysis, higher s value, immediate hanging wall/foot wall.

P. 45 Table A4-2 - Base m & s values.

P. 46 Figure A4-2 - Corresponding stability analysis using base values.

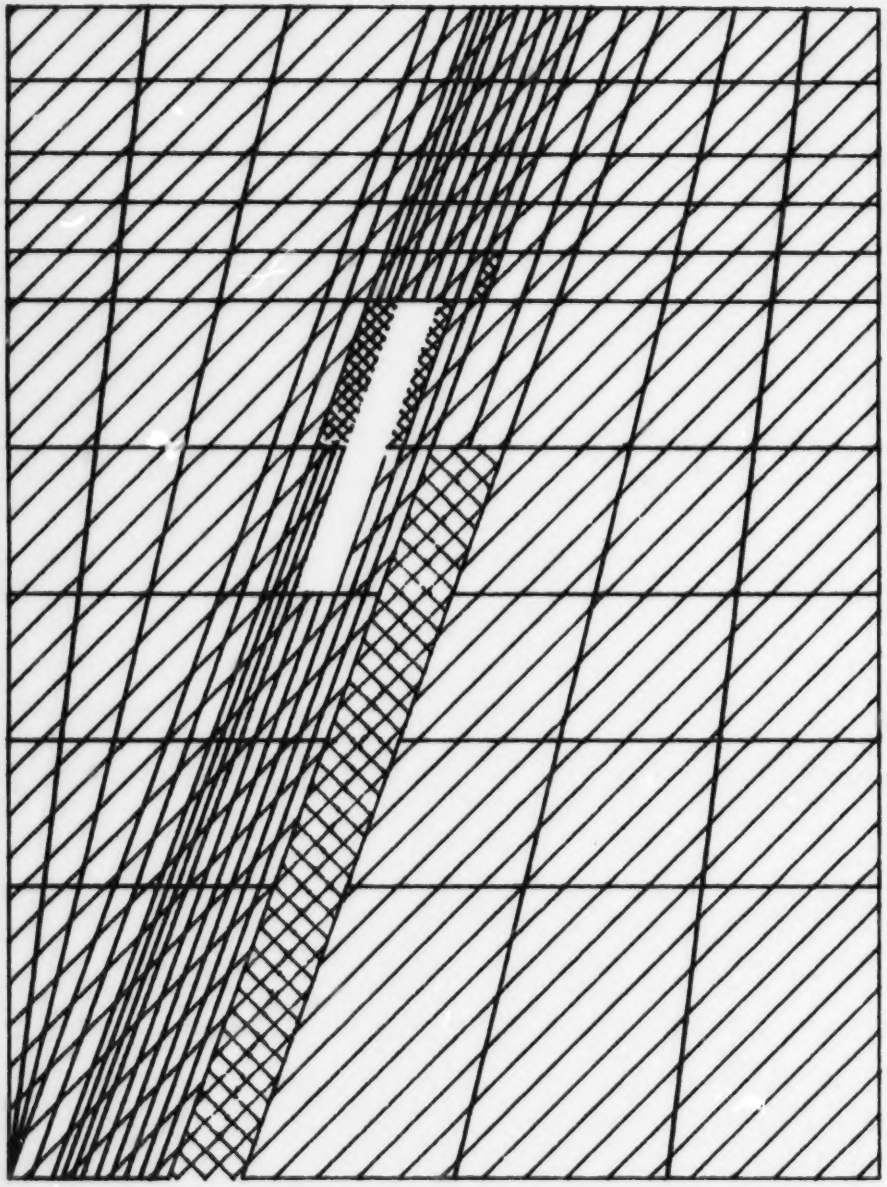
P. 47 Table A4-3 - Lower s value (0.002) immediate hanging wall/foot wall.

P. 48 Figure A4-3 - Corresponding stability analysis, lower s value, hanging wall/foot wall.

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.01	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

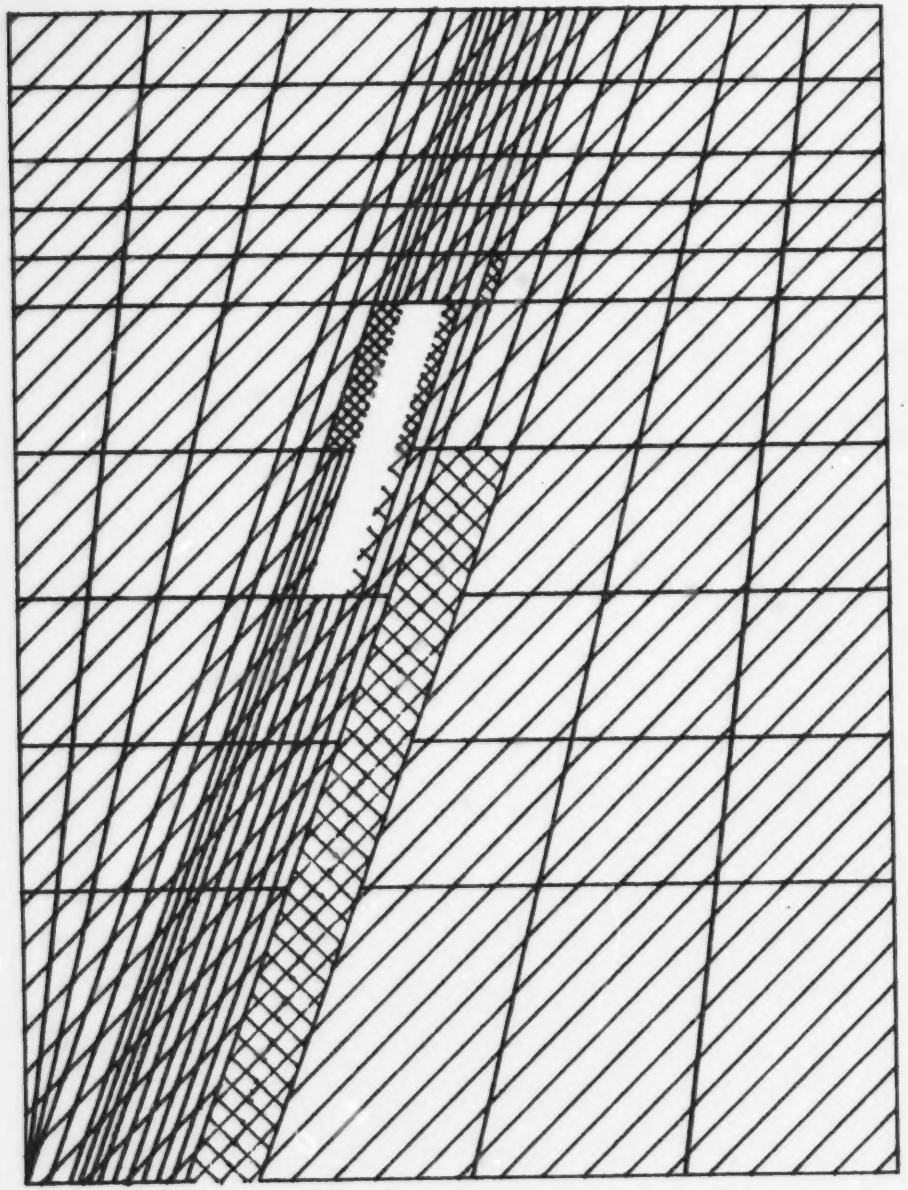
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

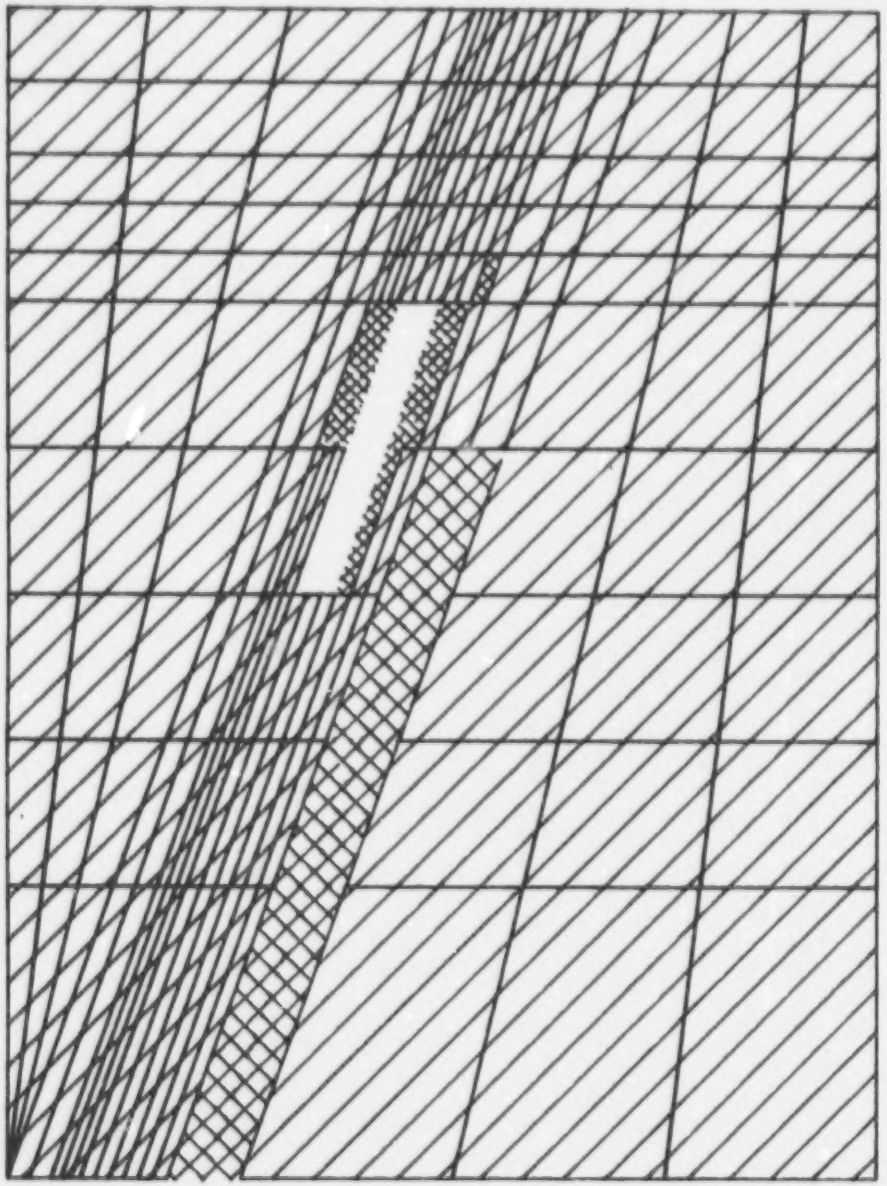
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.002	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

CRITICAL

SAFE

APPENDIX 5

STABILITY ANALYSES USING VARYING m & s VALUES, IMMEDIATE HANGING WALL/FOOT WALL

P. 51 Table A5-1 - Combined higher m and s values (3.2, 0.01), immediate hanging wall/foot wall.

P. 52 Figure A5-1 - Corresponding stability analysis, higher m and s values, immediate hanging wall/foot wall.

P. 53 Table A5-2 - Base m & s values.

P. 54 Figure A5-2 - Corresponding stability analysis, base values.

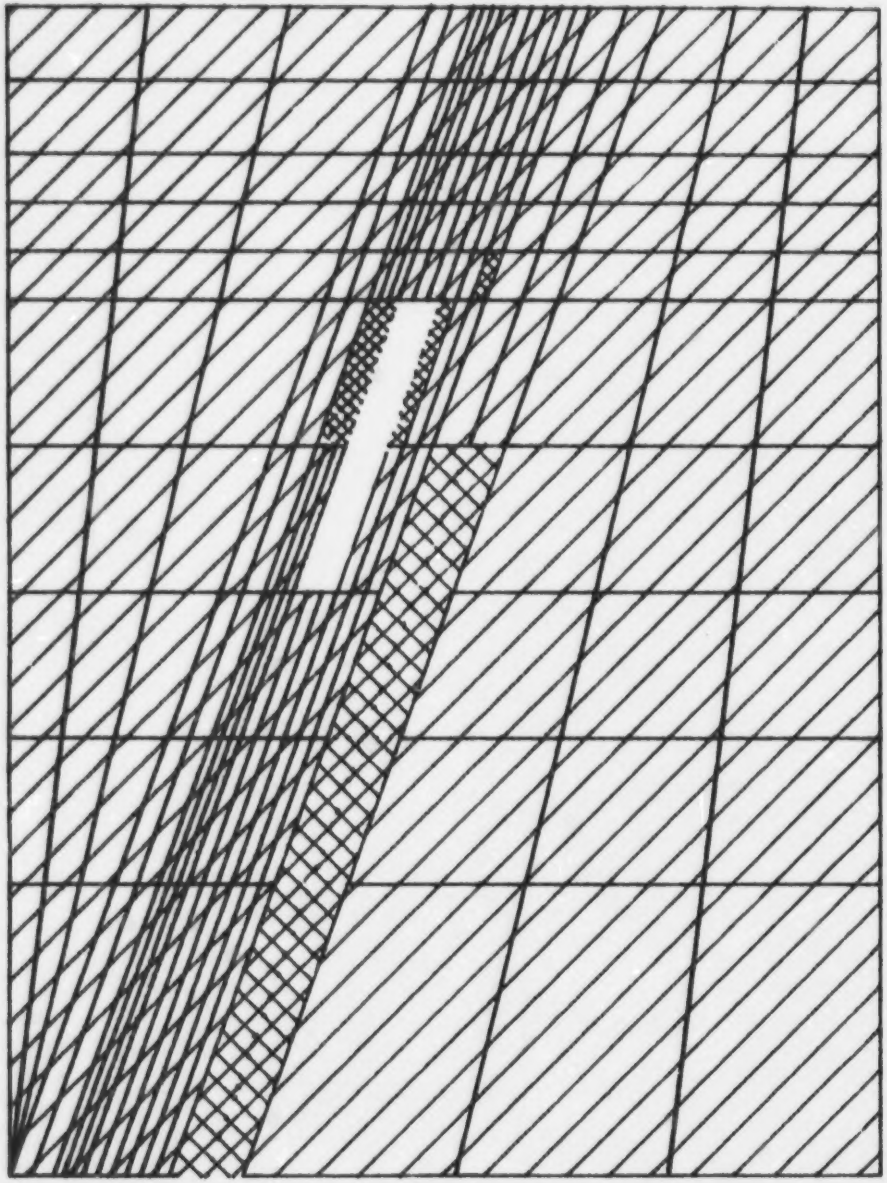
P. 55 Table A5-3 - Combined lower m and s values (1.4, 0.002), immediate hanging wall/foot wall.

P. 56 Figure A5-3 - Corresponding stability analysis, lower m and s values, immediate hanging wall/foot wall.

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	3.2	0.01	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

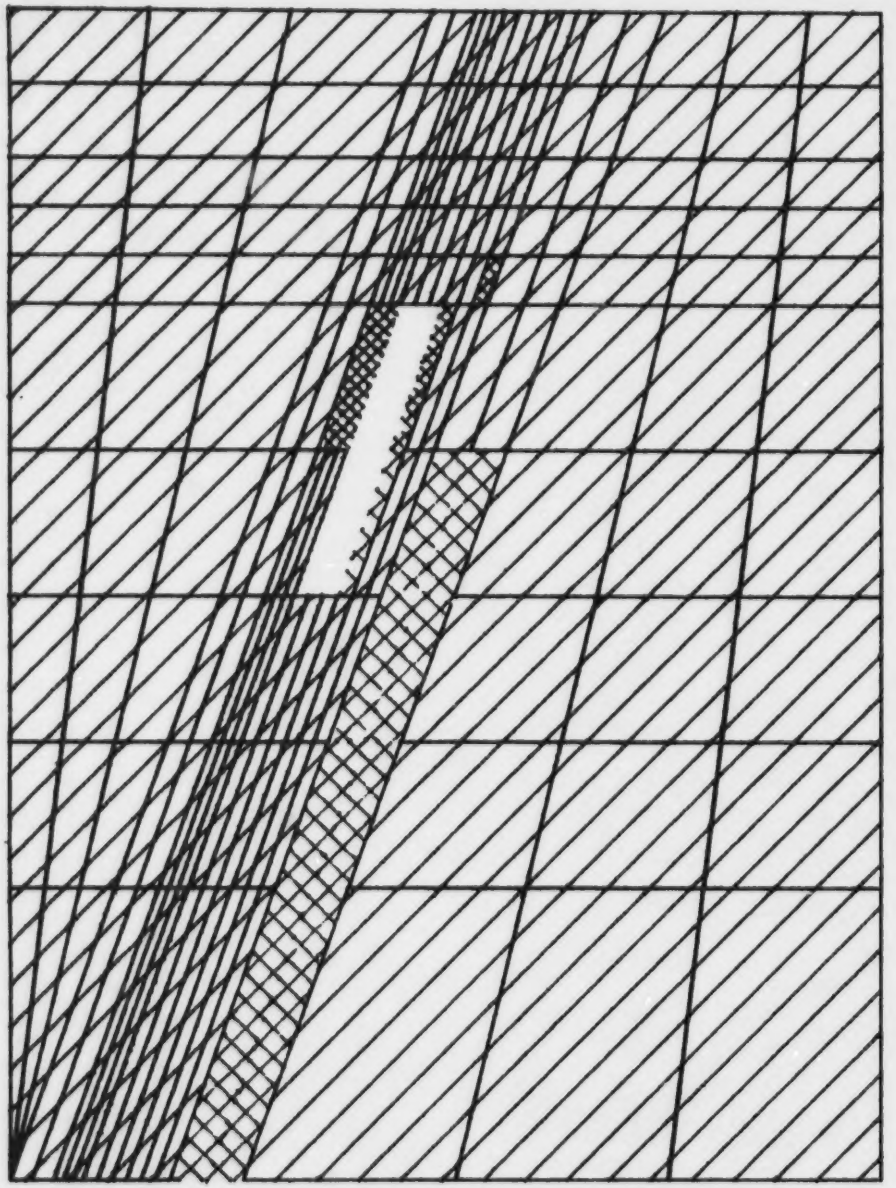
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

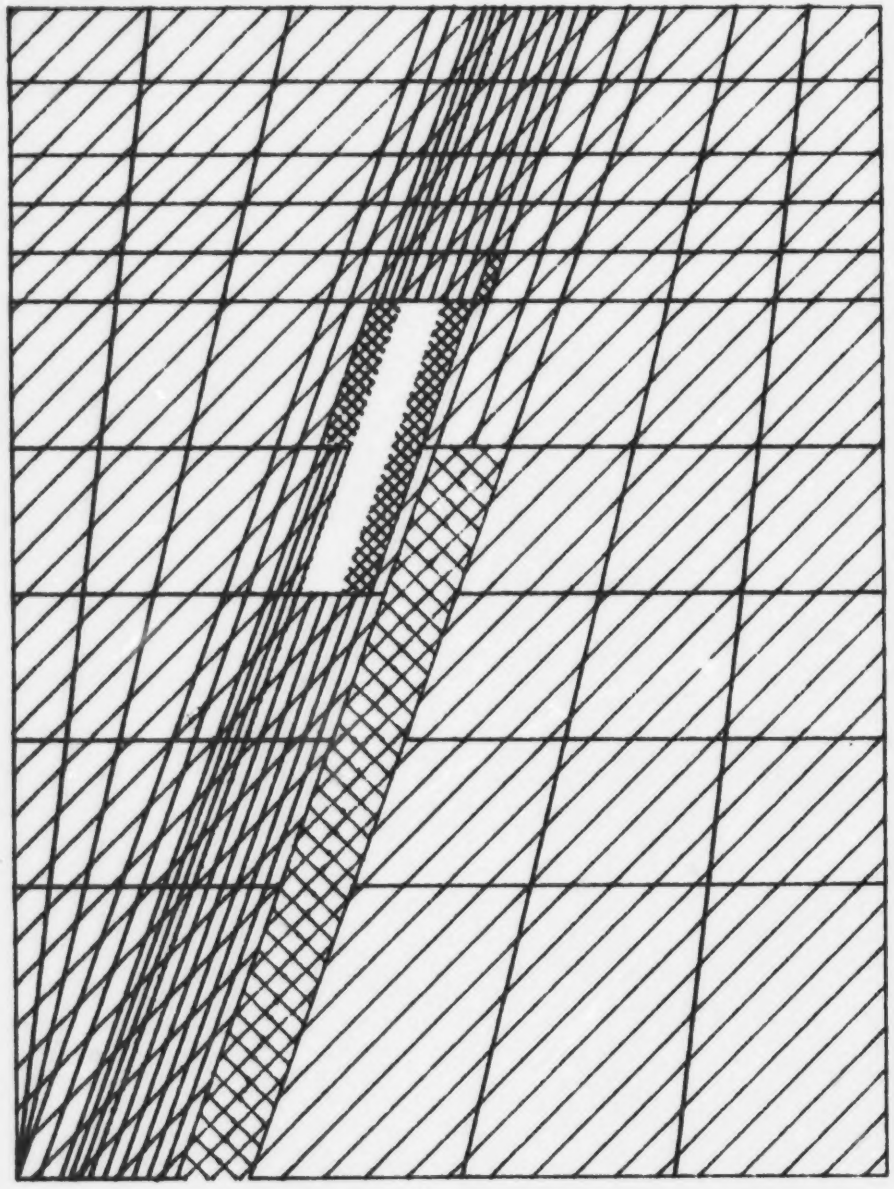
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	1.4	0.0002	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

CRITICAL

SAFE

APPENDIX 6

STABILITY ANALYSES USING DIFFERENT m VALUES, GRAPHITE SCHIST

P. 59 Table A6-1 - Higher m value (1.0), graphite schist.

P. 60 Figure A6-1 - Corresponding stability analysis, higher m value, graphite schist.

P. 61 Table A6-2 - Base m & s values.

P. 62 Figure A6-2 - Corresponding stability analysis, base values.

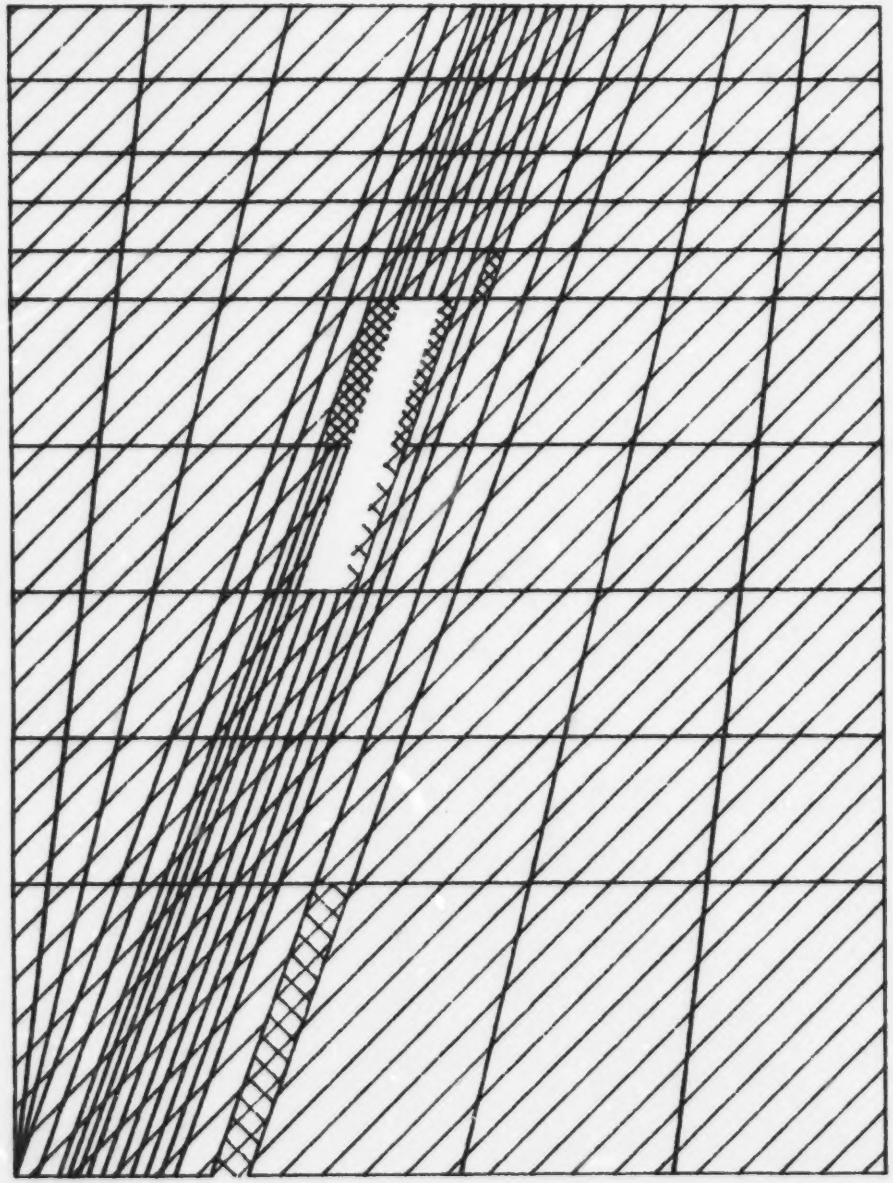
P. 63 Table A6-3 - Lower m values (0.1), graphite schist.

P. 64 Figure A6-3 - Corresponding stability analysis, lower m value, graphite schist.

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	1.0	0.0005	30



SAFETY

LEVEL

FAILED

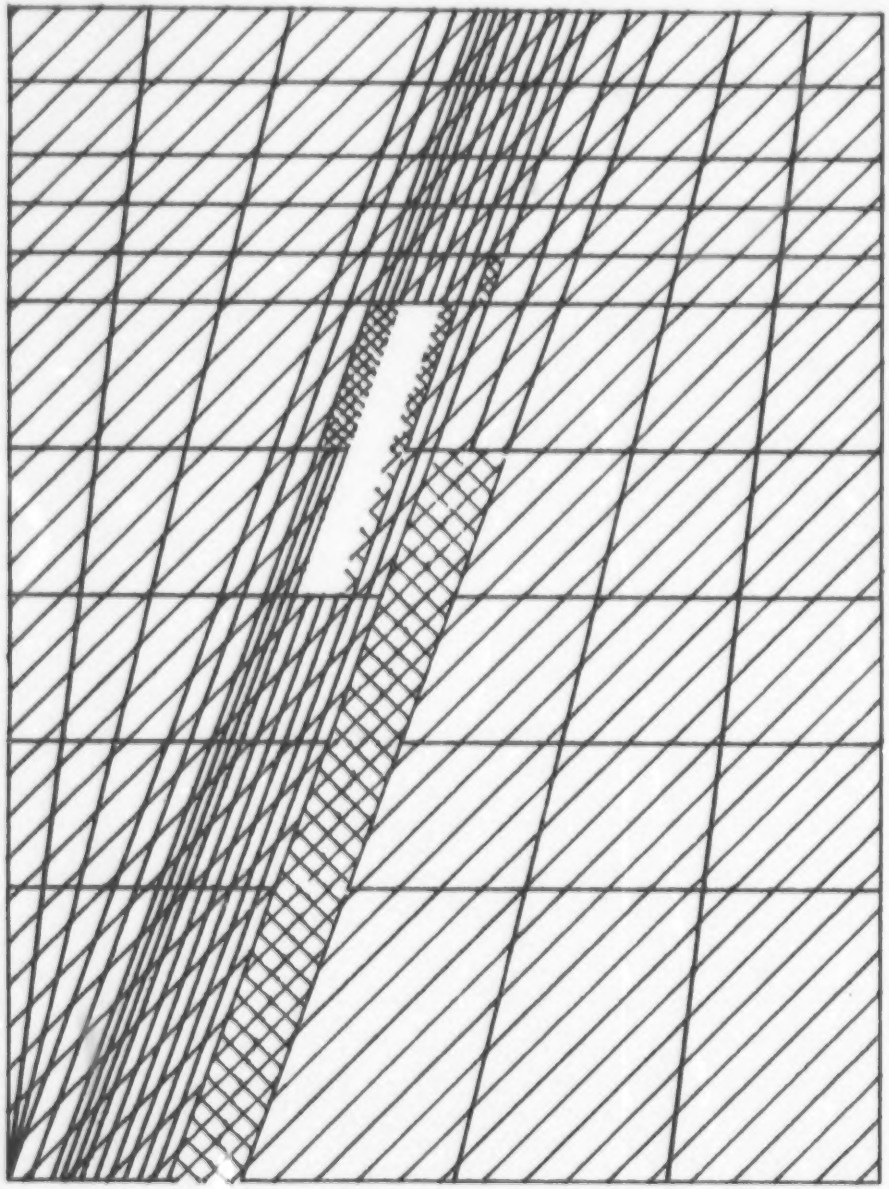
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

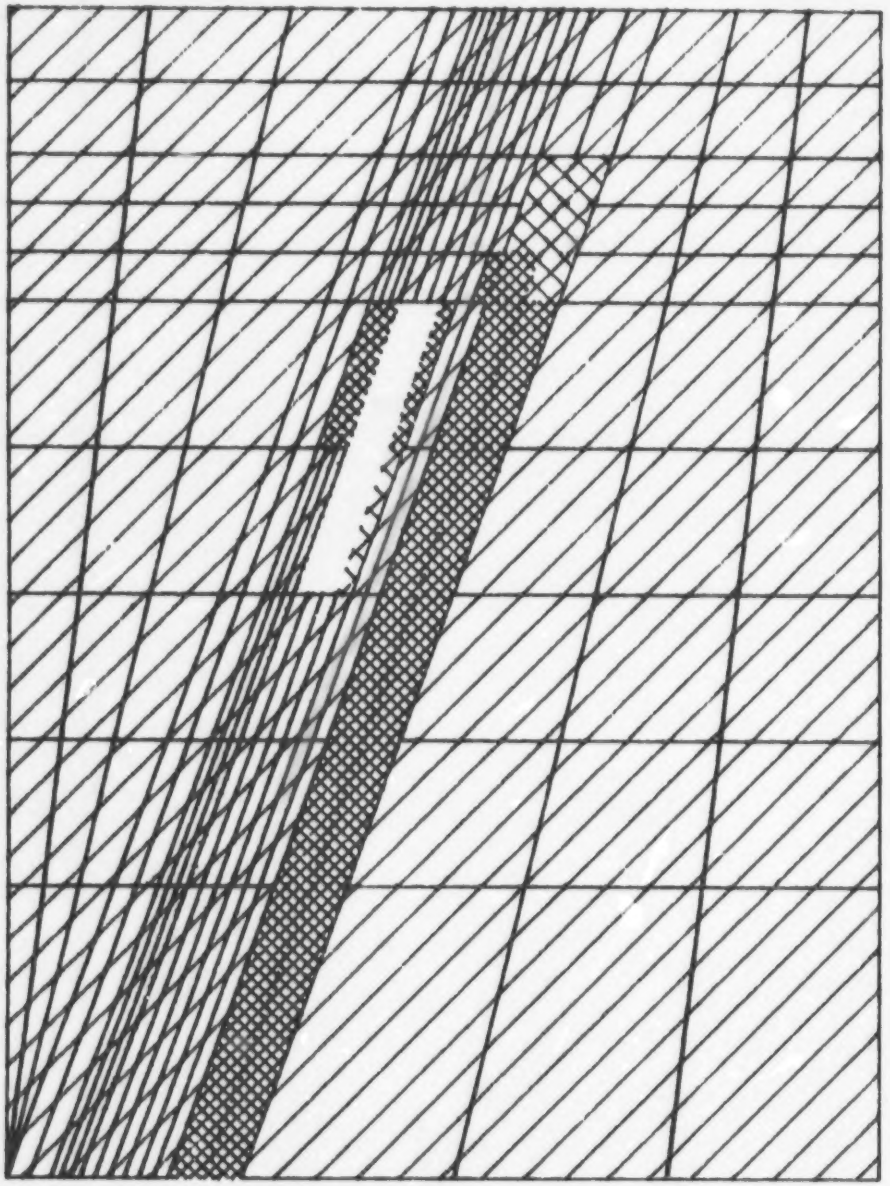
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.1	0.0005	30



SAFETY

LEVEL

FAILED

CRITICAL

SAFE

APPENDIX 7

STABILITY ANALYSES USING DIFFERENT a VALUES, GRAPHITE SCHIST

P. 67 Table A7-1 - Higher s value (0.01), graphite schist.

P. 68 Figure A7-1 - Corresponding stability analysis, higher s value, graphite schist.

P. 69 Table A7-2 - Base m & s values.

P. 70 Figure A7-2 - Corresponding stability analysis, base values.

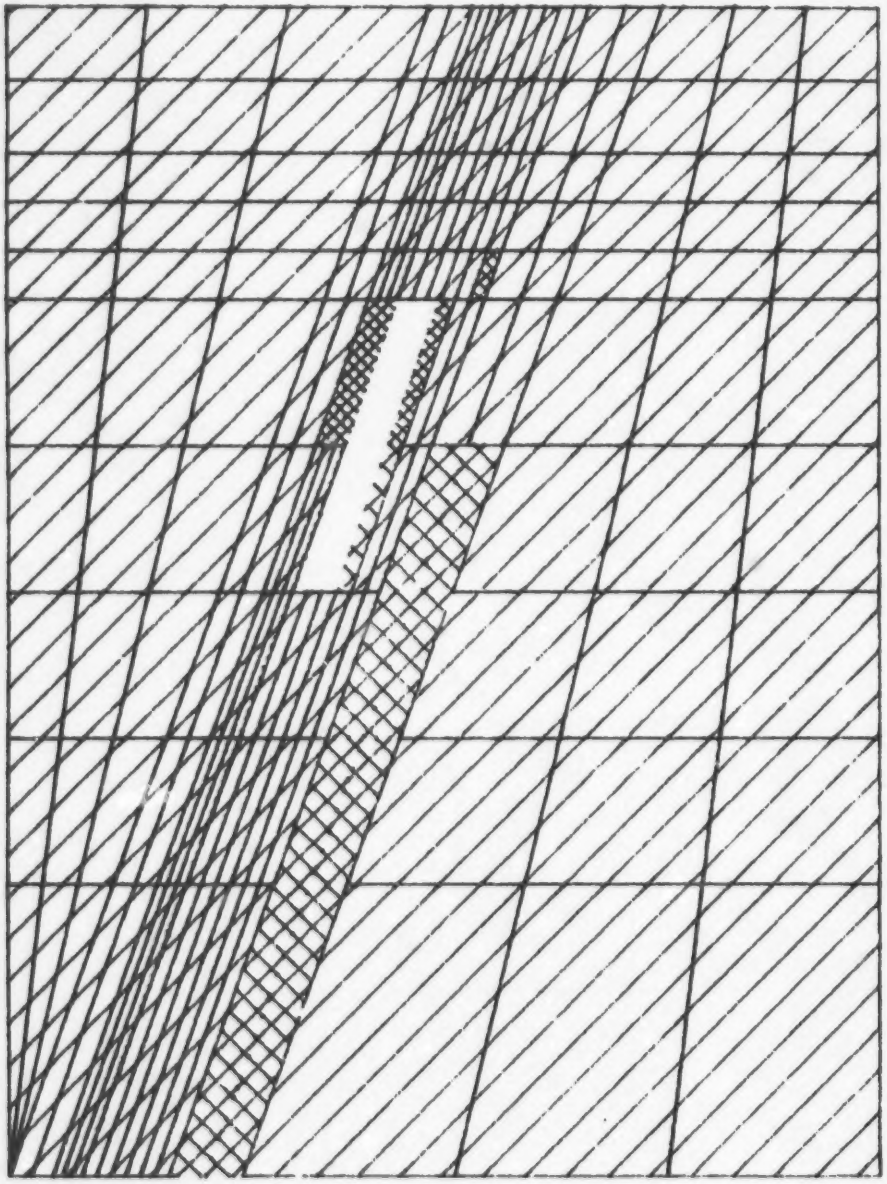
P. 71 Table A7-3 - Lower s value (0.0001), graphite schist.

P. 72 Figure A7-3 - Corresponding stability analysis, lower s value, graphite schist.

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.001	30



SAFETY

LEVEL

FAILED

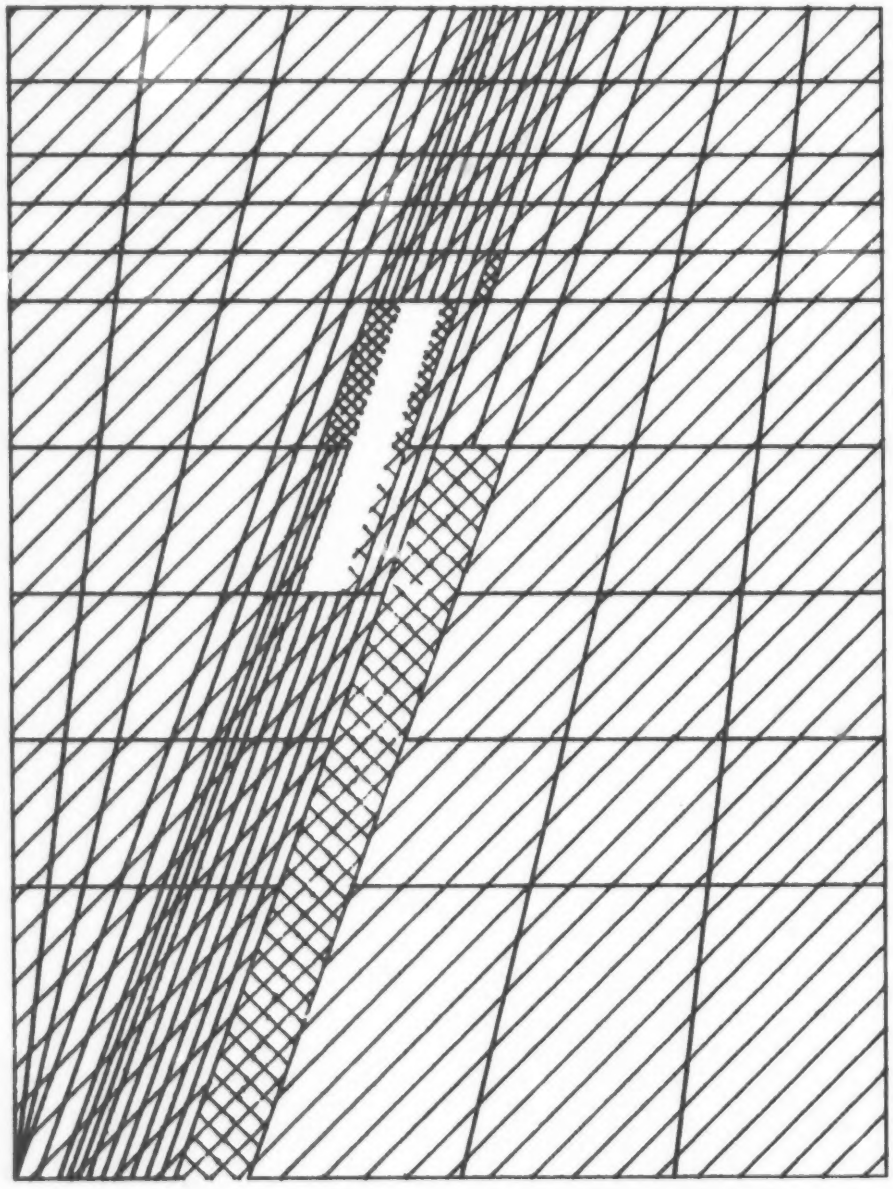
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

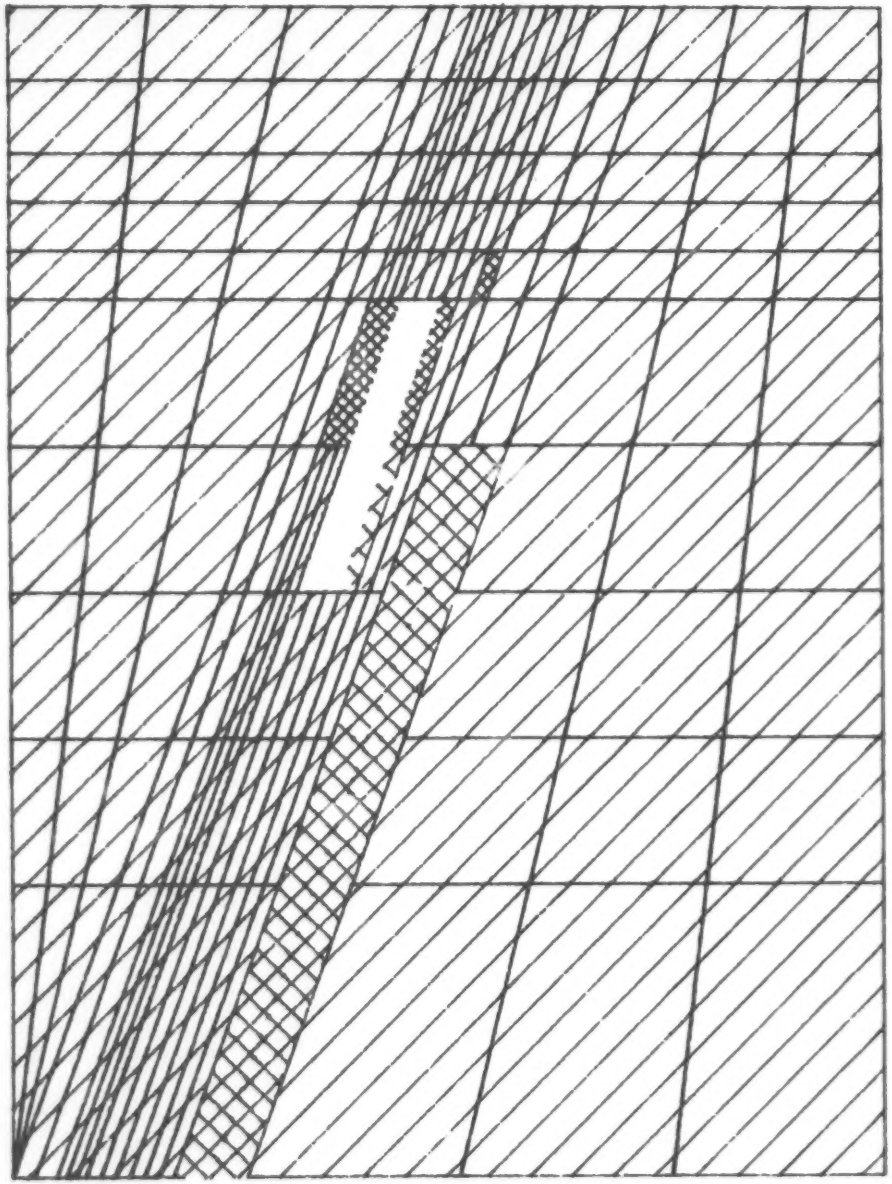
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0001	30



SAFETY

LEVEL

FAILED

CRITICAL

SAFE

APPENDIX 8

STABILITY ANALYSES USING VARYING m & s VALUES, GRAPHITE SCHIST

P. 75 Table A8-1 - Combined higher m and s values (1.0, 0.001), graphite schist.

P. 76 Figure A8-1 - Corresponding stability analysis, higher m and s values, graphite schist.

P. 77 Table A8-2 - Base m & s values.

P. 78 Figure A8-2 - Corresponding stability results, base values.

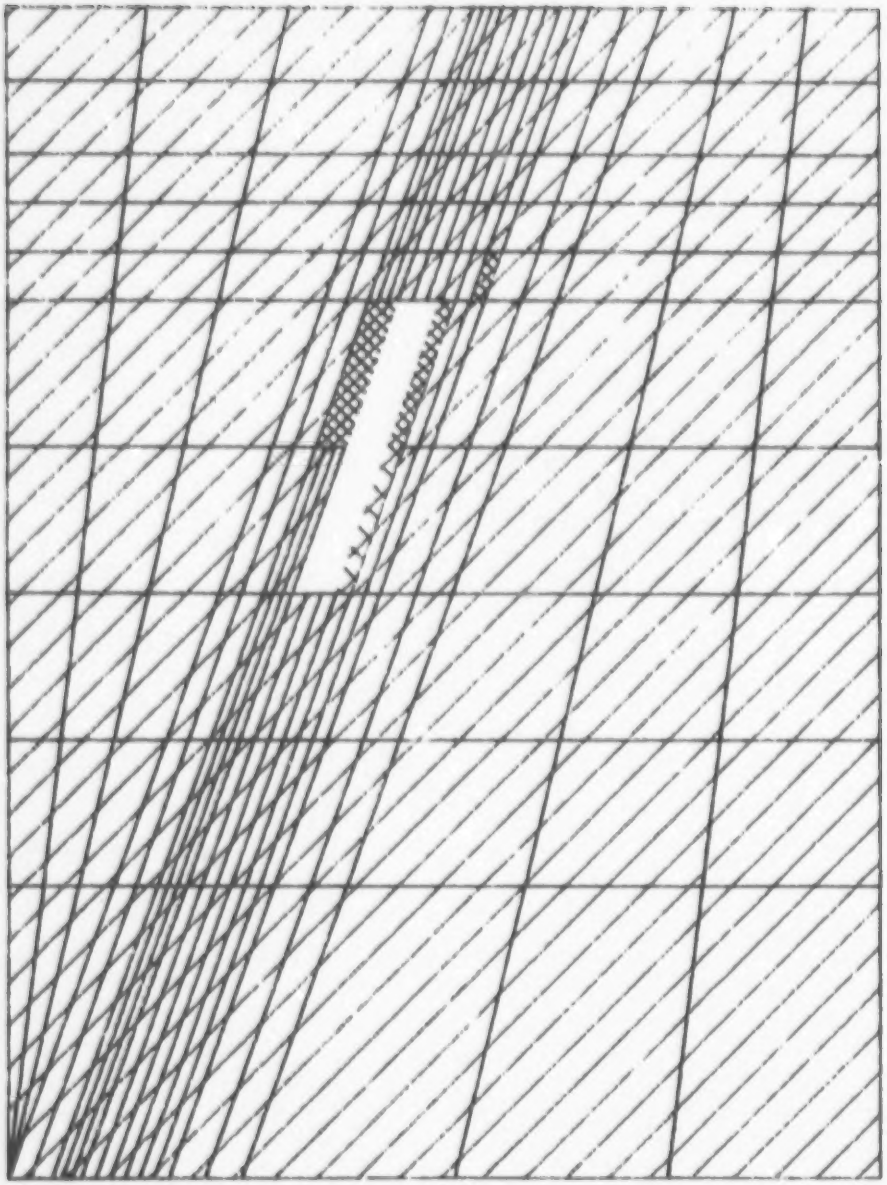
P. 79 Table A8-3 - Combined lower m and s values (0.2, 0.0001), graphite schist.

P. 80 Figure A8-3 - Corresponding stability analysis, lower m and s values, graphite schist.

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	1.0	0.001	30



SAFETY

LEVEL

FAILED

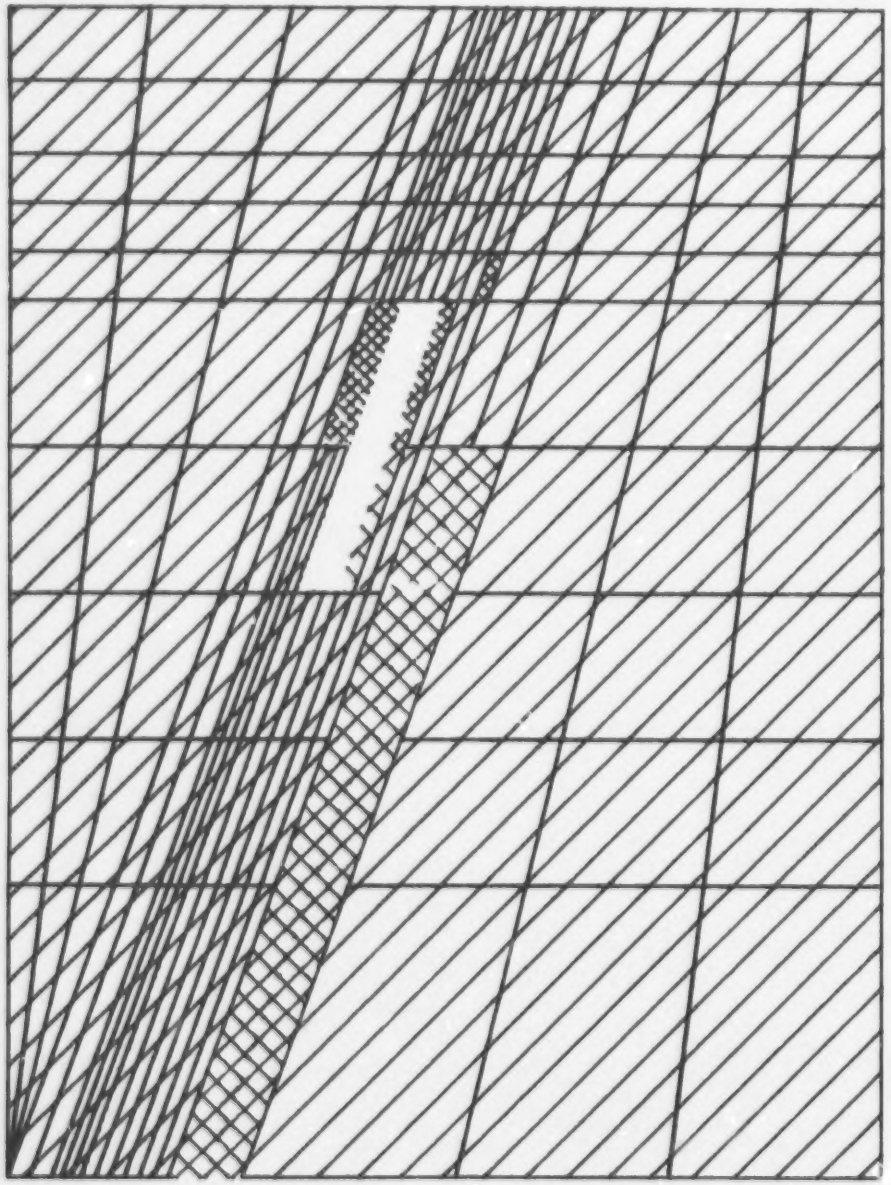
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.6	0.0005	30



SAFETY

LEVEL

FAILED

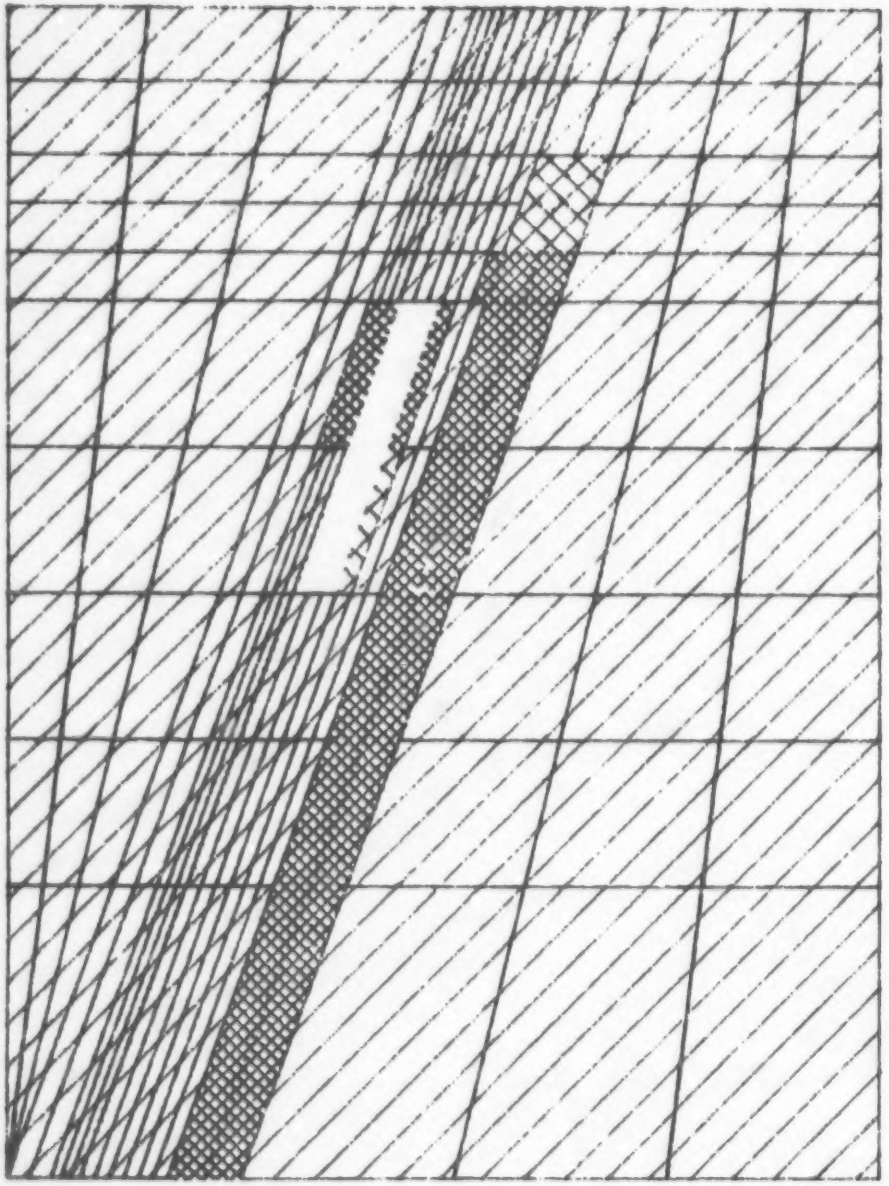
CRITICAL

SAFE

FAILURE CRITERIA	COEFFICIENTS		
	first	second	third
1.Mohr_Coulomb	C	Angle	
2.Drucker_Prager	C	Angle	
3.Hoek and Brown	M	S	Sigma C

TOTAL NO. OF MATERIAL TYPES = 5

MATERIAL NO.	FAIL. CRITERIA	COEFFICIENTS		
1	3	3.8	0.04	230
2	3	2.8	0.006	100
3	3	0.05	0.00001	0.15
4	3	3.2	0.02	200
5	3	0.1	0.0001	30



SAFETY

LEVEL

FAILED

CRITICAL

SAFE